SOIL DEGRADATION IN BRITISH COLUMBIA

PROCEEDINGS OF THE 8TH

B.C. SOIL SCIENCE WORKSHOP

FEBRUARY 17 AND 18, 1983

Province of British Columbia Ministry of Agriculture and Food

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Front Cover: Rill erosion in strawberries planted up and down a 10% slope in the Lower Fraser Valley.
Courtesy: R.C. Wood, BCMAF

SOIL DEGRADATION IN BRITISH COLUMBIA

Proceedings of the eighth meeting of the

British Columbia Soil Science Workshop

Held at the
Harrison Hotel, Harrison Hot Springs
February 17 and 18, 1983

Convening Committee

L.J.P. van Vliet
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J.C.W. Keng
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Held under the auspices of the B.C. Land Resource Science Lead Committee and the B.C. Engineering Science Lead Committee

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FOREWORD

The 8th British Columbia Soil Science Workshop was held in February, 1983 at Harrison Hot Springs, British Columbia to discuss "Soil Degradation in British Columbia". The purpose of the workshop was to create an awareness of soil degradation problems among soil scientists, foresters, agrologists, environmentalists and resource planners and to assess the seriousness of soil degradation in British Columbia. This was accomplished by one day of papers that focussed on causes, effects, extent, and remedial measures for the different kinds of soil degradation. In the morning of the second day, 3 buses took the workshop participants on a field trip to look at soil degradation problems in the Chilliwack Forest Region, Sumas Prairie, and Matsqui Municipality. The meetings continued in the afternoon with 9 working group discussions on different types of soil degradation, mainly regarding remedial measures and program policy and research needs.

The papers presented at the workshop and the summaries and recommendations of the discussion groups are published in this "Proceedings". Also included are: the workshop program, a list of participants, questions for working groups, tour route and tour description. This Proceedings, therefore, contains an up-to-date assessment of soil degradation in British Columbia.

The workshop was very timely, since in recent years an increasing number of people in B.C. are working on different aspects of soil degradation. The growing expertise and interest in soil degradation was clearly reflected by the number of workshop participants, which exceeded 150 for the first day.

Laurens J.P. van Vliet
Chairman,
Workshop Organizing Committee.

ACKNOWLEDGEMENTS

We would like to acknowledge Terry Lord, Head, B.C. Pedology Unit, Agriculture Canada; Les Lavkulich, Head, Soil Science Department, University of B.C.; Norm Sprout, Manager, Terrestrial Studies, Ministry of Environment; John Miltimore, Director, Agassiz Research Station; and Ron Bertrand, Director, Soils Branch, B.C. Ministry of Agriculture and Food, for their support of the workshop. We would also like to acknowledge Bob Louie, Manager, Ministry of Environment in Kelowna and Les Lavkulich for chairing some of the sessions. We would like to thank Lloyd Uzick, Agassiz Research Station, for his assistance in organizing workshop registration and coffee breaks. The Harrison Hotel, Harrison Hot Springs; East Chilliwack Coop, Chilliwack; and Green Valley Fertilizer Co., Surrey, are gratefully acknowledged for refreshments during coffee breaks. Also thanks to Les Anderson and Ralph Spragg, Chilliwack Forest District; Ron Bertrand and Martin Driehuyzen, B.C. Ministry of Agriculture and Food, Cloverdale, for contributing to the field tour.

The Workshop Organizing Committee

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PRESENTATIONS

OF

FEBRUARY 17, 1983

B.C. SOIL DEGRADATION WORKSHOP - OPENING REMARKS

R.N. Sprout, Chairman
Land Resource Science Lead Committee

Welcome to this Workshop on 'Soil Degradation'. I welcome you as chairman of the Land Resource Science Lead Committee which is co-sponsoring the workshop together with the Engineering Science Lead Committee.

It is a pleasure this morning to see so many in attendance in such a beautiful location. We should congratulate the Organizing Committee for choosing interesting agenda topics and a nice location in which to discuss them.

The theme of Soil Degradation was originally chosen by the Lead Committtee due to concern over certain erosion and acidification problems occurring in B.C. It has turned out to be quite topical because more recently there have been a number of initiatives in Canada and the U.S. which indicate a growing awareness of the importance of our maintaining the productivity of our land base. I suspect these may have been precipitated by such controversial issues as acid rain and urbanization of farm land.

At the Agriculture Ministers Conference in July, 1981, Mr. Whelan in his opening remarks commented that the soil base is important to the industry and to the national economy, and that land is basic to our future supply of food, our export sales and our entire economic and social development. Agriculture Canada has followed up on this concern by recently upgrading the priority given to land research aimed at maintaining and improving the quality of the farm land base.

The president of the Soil Conservation Society of America in their 1982 October/November newsletter stated that "The program thrust of the Society should be toward reducing land degradation." He then went on to say that "every effort should be made to maintain the productive capacity of land and water resources for food and fibre production and to avoid significant degradation of environmental quality through man's use of these resources".

Just a couple of months ago in December, 1982, the Canadian Federation of Agriculture convened a Soil Conservation Workshop in Ottawa. Their report states that present cropping practices are stressful to the land and that an

understanding of how to crop land in accordance with its capacity for permanent, sustained production should be the objective. The report also makes the interesting observation that "On present knowledge there is considerable scope for improved conservation practices by many farmers that could be beneficial to them even in the short run". The report infers that while research is still needed, particularly into the economic aspects of applying conservation measures, much can be done with our present state of knowledge.

This brings me back to the purpose of this workshop. While I have dwelt at some length on the agricultural aspects of the problem, the same principles apply to forestry, and over the next two days we hope to create an awareness of the soil degradation problems in B.C., both in agriculture and forestry. The workshop will provide an opportunity for professionals to share information on soil degradation. It is intended to facilitate discussion on soil degradation causes, effects, extent, and remedial measures, and to focus attention on the program, policy and research needed to overcome the problems.

In order to cover the concerns of both agriculture and forestry, the Organizing Committee has made a conscious effort to assemble a program which addresses both aspects. The major types of soil degradation are covered by the speakers. All speakers were requested to present their topic area in the following manner:

a) identification and description of the degradation problem (causes)

b) the effects of the degradation problem

c) an assessment of the problem for British Columbia

d) suggested remedial measures

This unified approach will, I am sure, help everyone to concentrate on the causes, effects, extent and remedial measures related to the various soil degradation processes.

After having mentioned the Organizing Committee several times, I would finally like to recognize and publicly thank them for their time, initiative and leadership in planning and organizing this two-day workshop. The committee members are:

Mr. Laurens van Vliet, Agriculture Canada, Vancouver, Chairman

Dr. John Keng, Agriculture Canada Research Station, Agassiz, Secretary, and in charge of registration, and who was assisted in this task by Mr. Loyd Uzick of the same institution

Mr. Craig Wood, B.C. Ministry of Agriculture and Food, Cloverdale, in charge of tours

Dr. Michael Novak, Department of Soil Science, U.B.C.

The committee tells me that Proceedings of the workshop will be compiled and distributed to all those who have registered.

With these few comments I welcome you and trust that the workshop will be an interesting and productive exercise.

B.C. SOIL DEGRADATION WORKSHOP - OPENING REMARKS

J.F. Metzger, P. Eng.
Secretary, Engineering Science Lead Committee

Engineers working with the renewable resource industries are often involved in the application of engineering principles to solve soil and water management problems. We seek to use the soil and water without waste to provide for high levels of production. In agriculture, for example, engineers are called upon to create proper soil environments for optimum plant production. We interact with the soil in many activities:

Land development. Engineers are asked to advise on land clearing, reclamation and range development methods and equipment. The way land development takes place can affect the agricultural productivity of the soil for many subsequent years.

Agricultural mechanization. Crop production equipment for tillage, seeding and harvesting affects the production capability of the soil directly and indirectly.

Soil erosion. Engineers are called upon to implement soil conservation practices such as contouring, strip cropping and terracing.

Manure management. Engineers develop systems to collect, store and apply manure to the soil for crop production and pollution control.

Water management. We design drainage and irrigation systems to provide optimum soil moisture levels for crop production.

Sound soil and water management requires an understanding of soil and plant sciences as well as engineering principles. To be fully effective as professionals we must have an appreciation for each other's expertise and problems. To solve these problems we must cooperate wherever possible, as few problems can be solved within the limits of any one profession. It is my hope that this workshop will result in a better understanding of the problems we each face and in a spirit of cooperation, result in constructive solutions.

SOIL DEGRADATION IN CANADA - AN OVERVIEW

D.R. Coote
Land Resource Research Institute
Agriculture Canada, Ottawa

INTRODUCTION

The term "soil degradation" was seldom heard just five years ago. Today it is widely used, often to reflect slightly different situations which depend on the view-point of the user. In this brief review, it is intended to outline the major types of soil degradation being experienced in Canada today. An attempt is also made to indicate the relative state of knowledge about these various problems across the country, while leaving the situation in British Columbia for the discussions later in this workshop.

WATER EROSION

This is the most widely distributed and well recognized manifestation of soil degradation. It is also the one for which most data are available, although these data are still depressingly inadequate. In the Prairies, for example , Toogood (1963) measured water erosion in the Edmonton area back in the 50's. He showed that although prairie climatic conditions resulted in great variability in runoff and erosion, the widespread wheat-summerfallow system consistently resulted in the greatest soil erosion (average 1.5 t ha^{-1} yr^{-1}). Rotations of grain and hay had far lower rates (e.g. 3 yr grain - 2 yr hay rotation average 0.035 t ha^{-1} yr^{-1}). Short, intense summer

storms resulted in erosion rates as high as 4 t ha^{-1} in one hour on summerfallow. Unfortunately, Toogood's work did not assess erosion during the snow-melt period. Recent work by De Jong et al (1982), using the ^{137}Cs method, suggests that average erosion of knolls in the Saskatoon area has been as high as 5.75 t ha^{-1} yr^{-1} under the grain-summerfallow system since the 1960's.

In eastern Canada there are data which show that monoculture corn, especially on sloping land, seems to be about the most seriously eroding cropping system (average of 19-49 t ha^{-1} yr^{-1} on 7-10% slopes in Ontario) (Ketcheson and Webber, 1978; Ripley et al, 1969), although potatoes in Prince Edward Island and Quebec have been shown to erode at rates almost as severe (e.g. 6-20 t ha^{-1} yr^{-1} on slopes ranging from 12-15%) (Dubé, 1975; Himelman and Stewart, 1979). Erosion in potatoes in New Brunswick is believed to average about 20 t ha^{-1} yr^{-1}(Stewart, 1976). Cropping systems based on rotations of row-crops with hay and small grains have lower erosion rates, not only in terms of the average annual loss over the period of the rotation, but also in the years in which corn is grown, suggesting that soil structure benefits from the years of close-grown crops are carried over to the row-crop years.

The Universal Soil Loss Equation (USLE)

This United States equation is well known to those concerned with water erosion. It is as follows:

$$A = R\ K\ L\ S\ C\ P$$

where: A is soil erosion, R is a rainfall erosivity factor, K is a soil erodibility factor, L and S combine as a slope and length factor, C is a cropping coefficient and P depends on the presence or absence of conservation practices (Wischmeir and Smith, 1965). The USLE has presented problems in Canada, mainly because:

a) It does not take account of snowmelt runoff. Except for some research in southern Ontario (van Vliet and Wall, 1981), Canadian

studies have generally indicated that the snow-melt period is very significant as a factor in soil erosion.

b) It assumes that soil erodibility is constant for any given soil type, but research currently underway suggests that soil erodibility is highly variable, depending on seasonal conditions. Hopefully, these problems will soon be overcome, and a USLE modified for Canadian conditions will be available.

Total Canadian Soil Loss

To attempt an estimate of the total loss of soil by water erosion in Canada may be foolhardy, but is interesting nevertheless! Based on a simplified application of the USLE, it is possible to arrive at a figure of about 155 million t yr^{-1}. If it is assumed that new soil is being generated at a rate of 0.50-0.75 t ha^{-1} yr^{-1} (from soil depth developed since the retreat of glaciation), then the net loss of soil in Canada is about 130 million t yr^{-1}. Of course, much of this soil is redistributed, and does not necessarily leave the country! Using a somewhat different approach, the Prairie Farm Rehabilitation Administration (PFRA, 1982) has recently estimated the soil loss by water erosion in the three Prairie Provinces to be about 117 million t yr^{-1}.

Trends in Water Erosion in Canada

In the humid areas of Canada, the current trend seems to be for increasing soil erosion as a direct result of increasing the area of monoculture corn (and soybeans), increasing the size of fields and reducing the use of rotations based on a sod crop.
In the prairies there is a trend toward decreased water erosion as a result of the reduction (in recent years) of summerfallow area and the increasing use of minimum tillage. To partly offset this trend, however, is a continuing decline in organic matter in many summerfallowed and eroded areas, leaving the soil less resistant to erosion.

The extension northward of cultivation provides considerable potential for increased water erosion, especially during snowmelt and early spring rains.

WIND EROSION

Wind erosion has always been thought of as a "prairies problem", and more especially as one of the 30's. Now it seems to be recurring with increased frequency, and is even becoming a problem in Ontario. It is a phenomenon on which we have very few measured data in Canada. Most of those available elsewhere are based on extrapolations from laboratory or wind-tunnel studies. In Manitoba, Jenkins (1982) measured the soil deposited in a road ditch downwind of a field which had been drifting for 2 days. The wind had moved 160 t ha^{-1}, and this did not include the fine dust blown beyond the ditch. Making some very simple estimates based on U.S. experience, the PFRA (1982) came up with an estimate of 160 million t yr^{-1} for the Canadian Prairies. Other estimates (Coote, unpublished), place the loss of soil by wind erosion at a somewhat lower level, i.e. about 60 million t yr^{-1} for all of Canada.

Wind erosion prediction

Is it possible to predict wind erosion from the work of W.S. Chepil, a pioneer researcher in the 30's, and this is commonly done in the U.S. with a simplified annual equation (Woodruff and Siddoway, 1965). Recently attempts have been made to improve upon this approach and make it more relevant to Canadian conditions by incorporating some of the results of Bisal and Hsieh (1966) at Swift Current (Coote, unpublished). An equation of the form:

$$E = K(V_*^2 - \gamma W^2)^{1.5}$$

has been used, where E is erosion rate, V_* is the drag velocity of wind at the surface of a smooth soil, W is equivalent soil moisture

content, and K and γ are constants depending on the soil type and the condition of its surface. Attempts are currently being made to map the wind erosion risk for the most susceptible months of April and May in western Canada.

Trends in Wind Erosion in Canada

There has been a trend in recent years for wind erosion to become more common (1976 and 1981 were particularly serious) and to become a significant concern in Ontario and even in Quebec. On the prairies, the future trends seem to be closely linked with the amount of summer-fallow and the degree to which minimum and zero tillage are adopted. In Ontario and Quebec, continuing fence-row removal and field size enlargement, and use of monoculture row crops with fall plowing, will continue to increase the frequency and severity of soil drifting, especially on sandy soils. Elsewhere in the humid areas of Canada, the wind erosion risk will probably remain low.

SOIL COMPACTION

Soil compaction, often associated with the loss of stable soil structure, has been observed with increasing frequency in recent years, especially in the more humid parts of Canada. It appears to be caused by excessive tillage, tillage of moist soils, frequent vehicle traffic and harvesting operations on wet soils. It is sometimes associated with low soil organic matter levels, but it may be that the type of organic matter is more important than the quantity. Soils used for corn in eastern Ontario and southern Quebec, for example, can have fairly high total soil organic matter levels, yet have very poor structure (Coote and Ramsey, 1983). This restricts water movement and root penetration leading to greater damage to crops by excess moisture in the spring or following heavy rains, and by moisture stress during dry periods. The risk of field operations being

carried out under wet surface conditions is also increased. It has been observed elsewhere (Reid and Goss, 1981) that corn is particularly damaging to soil aggregate stability compared with other crops. The exact reasons are still being investigated, but supression of microbiological activity by corn roots appears to be involved. It seems that the problem of increasing compaction under corn can be alleviated, at least in part, by crop rotations.

Assessment of soil compaction

A number of measurements of soil physical parameters may be used to quantify soil structure. These include the distribution of pore space, hydraulic conductivity, bulk density, oxygen diffusion rates and penetrometer resistance. Water stable aggregates can also indicate the stability of soil micro-structure. All of these approaches have their limitations, and there are few comparable data for situations across the country from which to make a general quantitative assessment. Figure 1 shows the effect of over 35 years of tillage of a sandy loam soil for corn in eastern Ontario. The soil pore space has shifted from larger to smaller pores, with a reduction in the total and air-filled pore space, and an increase in the moisture content at field capacity and at higher tensions (Coote and Ramsey, 1983). We will need many more data before useful comparisons between soils and cropping practices can be made.

Trends in Soil Compaction in Canada

Soil compaction is increasingly described by farmers as a high priority concern. It appears to be increasing with the use of monoculture, and especially with corn, sugar-beet, potatoes and vegetable crops such as peas. If these crops, especially corn, continue to be shifted into wetter areas with shorter growing seasons, the problem of soil compaction is almost certain to increase. If soil organic

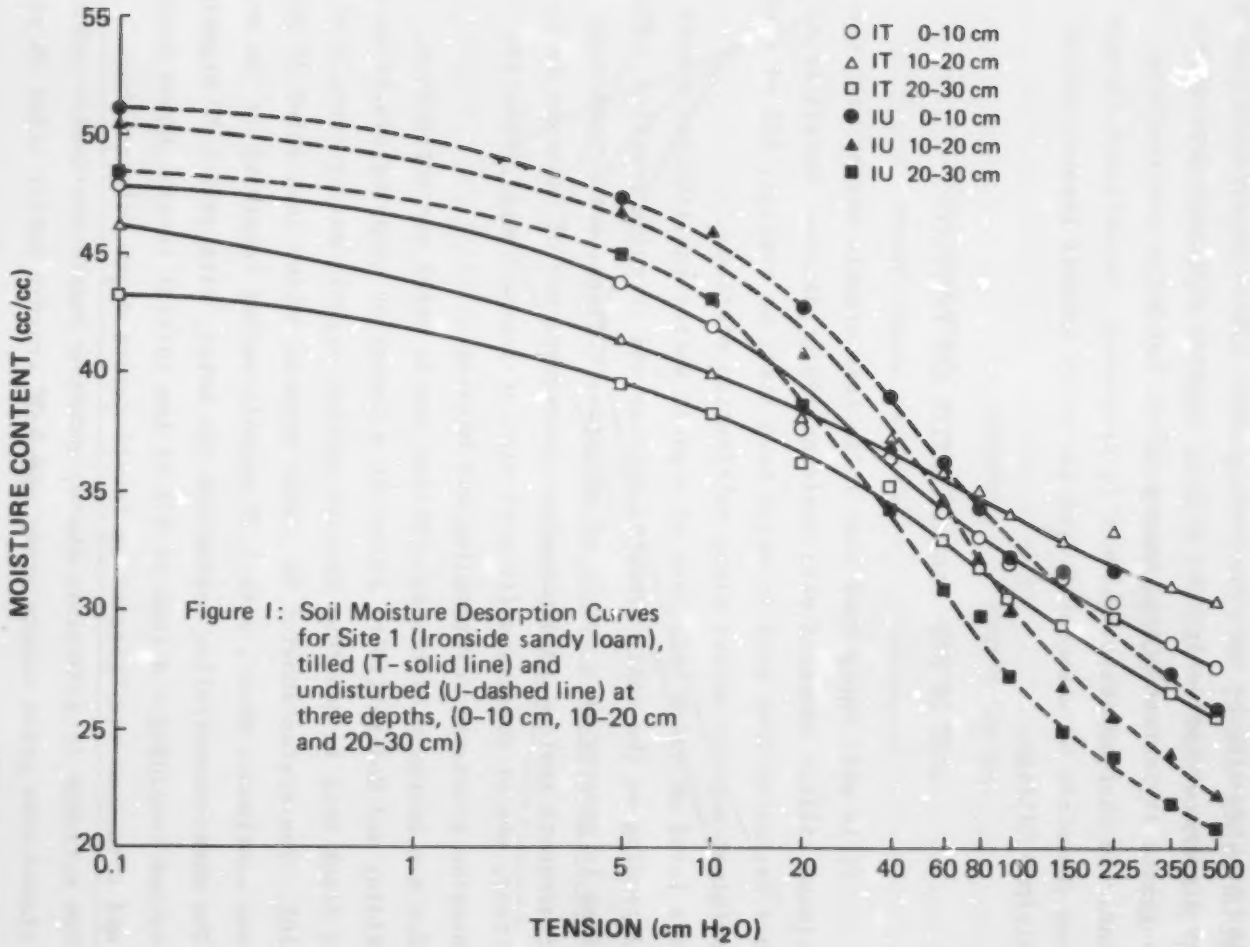


Figure 1: Soil Moisture Desorption Curves for Site 1 (Ironside sandy loam), tilled (T-solid line) and undisturbed (U-dashed line) at three depths, (0-10 cm, 10-20 cm and 20-30 cm)

matter levels continue to decline, as for example with silage corn, the problem will be even more noticeable. There is a lack of clarity at present concerning the role of minimum tillage. Some work suggests it increases soil bulk density, but other observations indicate that moisture movement is increased. No definite changes can therefore be associated with the trend towards greater use of minimum tillage.

LOSS OF SOIL ORGANIC MATTER AND FERTILITY

It is well recognized that soils lose organic matter with continued tillage compared with their native condition. McGill et al (1981) has estimated that prairie soils have lost, on average, 45% of their original organic matter since cultivation started.

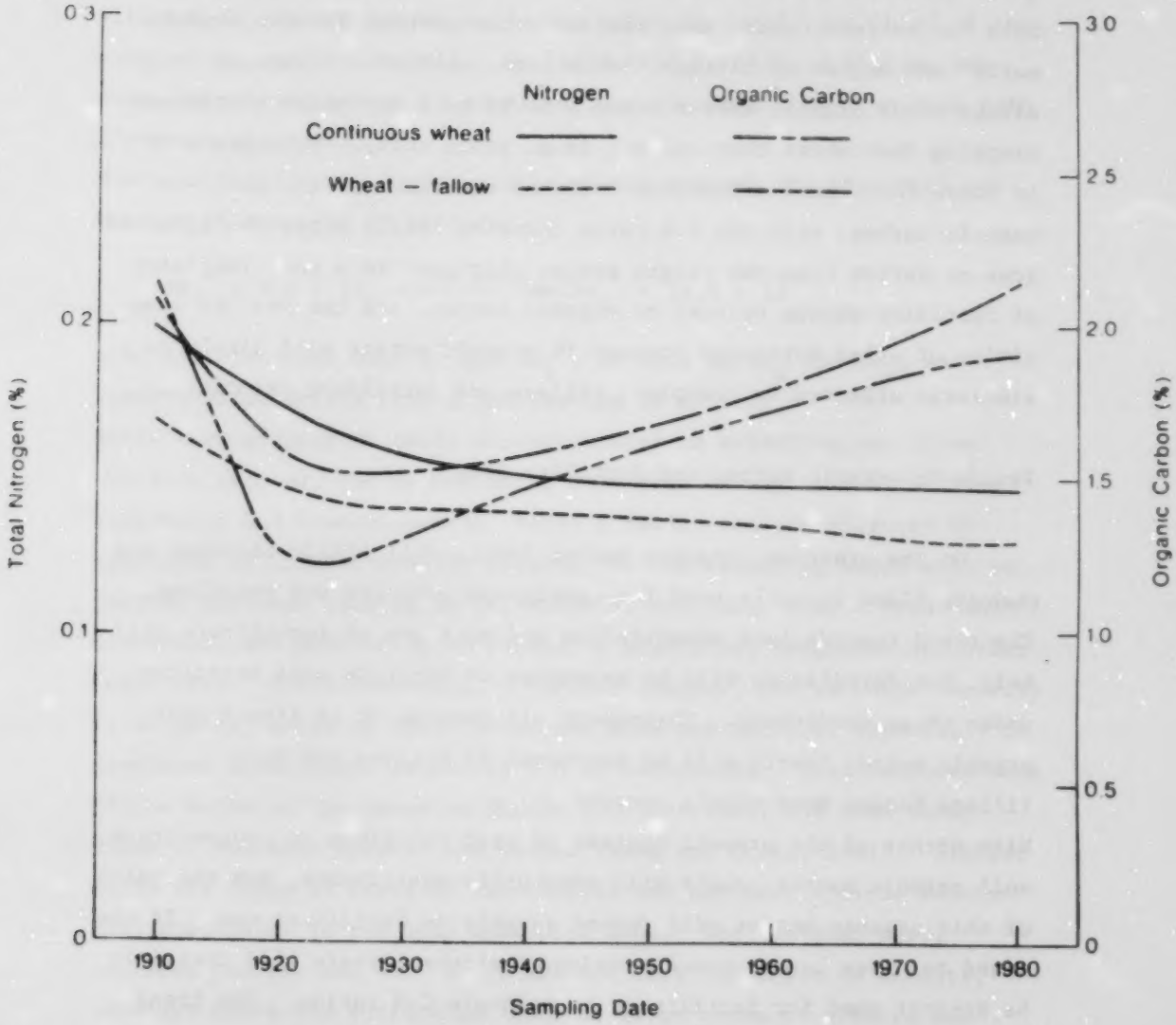
The level at which this loss of organic matter equilibrates varies depending on the soil, climate, tillage and cropping practice. The loss is greater as a result of excessive tillage, summerfallowing, inadequate residue incorporation, inadequate use of nitrogen fertilizer, use of rotations (if any) without legume crops, selective erosion processes, overgrazing and burning.

For a comparison of the equilibrium levels which are approached, Ridley and Hedlin (1968) looked at a number of cropping practices on a Black soil in Manitoba with an initial organic matter content of 10%. The system showing the least organic matter loss after 37 years was continuous wheat, with 7.2% organic matter remaining in the soil. The wheat-summerfallow system was the worst, with only 3.7% organic matter remaining - a loss of 63% of the initial level. Other crops and rotations equilibrated at levels intermediate between these two extremes (e.g. 3 years wheat, with one year summerfallow and a plowed-down green manure grass had 6.0% organic matter after 36 years, a loss of 40%).

Figure 2 shows that prairie soil organic matter can be maintained under continuous wheat, and even under a wheat-fallow system, if

FIGURE 2.

Soil organic matter and nitrogen levels at Lethbridge, Alberta under continuous wheat and a wheat – fallow rotation over a 70-year period



From data of:

Freyman, S., C.J.Palmer, E.H.Hobbs, J.F.Dormaar, G.B.Schaalje and J.R.Moyer. 1982. Yield trends on long-term dryland wheat rotations at Lethbridge. Can.Jour.Plant Sci. 62(3):609-620.

there is a high yielding crop to supply plenty of residue, and the soil is not excessively tilled. Organic nitrogen contents, however, appear to continue to fall steadily unless nitrogen fertilizers are used. Thus the organic matter will likely become poorer in its nitrogen supplying capability under continuous cropping, even though gross quantities may be maintained.

Data for eastern Canada show similar relationships between organic matter and degree of tillage. When corn residues are removed (e.g. silage corn) organic matter seems also to be lower under continuous cropping than where they are not (e.g. grain corn). Nitrogen loss in these fertilized situations followed the same pattern as organic carbon, with the C:N ratio changing little after the original loss of carbon from the virgin state. Nitrogen is a good indicator of fertility status related to organic matter, and the smaller quantities of other nutrients present in organic matter will likely be similarly affected by cropping, tillage and fertilizer practices.

Trends in organic matter and fertility loss

On the prairies, organic matter levels will likely increase and then stabilize in soils used for continuous cropping and rotations. The trend towards less summerfallow and more use of fertilizers will help, but fertilizers will be necessary to maintain soil fertility under these conditions. Throughout all regions it is likely that organic matter levels will be increased if minimum and zero tillage become more widely accepted.

With either of the present systems of crop rotations or monoculture, soil organic matter levels will eventually equilibrate, but the value of this organic matter will depend largely on fertilizer use. If the trend for less legume-based rotations continues, there will certainly be greater need for fertilizers to maintain C:N ratios. The trend towards increased soil erosion in the humid regions will, unfortunately, accelerate organic matter loss.

ACIDIFICATION

Acidification is a natural process in humid region soils, but in recent years it has been receiving attention as a degradation process because it is accelerated by nitrogen fertilizer use and acid rain. Nitrogen fertilizer use is by far the greatest factor nationally, although in eastern Canada acid rain makes up nearly one third of the man-induced acidity overall. On individual fertilized fields, however, fertilizer generally supplies 5 to 10 times that from acid rain (Coote et al, 1981).

Nitrogen fertilizers cause acidity mainly through the microbial conversion of ammonium to nitrate:

$$NH_4^+ + H_2O + 2O_2 \xrightarrow{\text{bacteria}} NO_3^- + 2H_2O + 2H^+$$

Acid rain contains both H^+ and NH_4^+, as well as SO_x and NO_x, so acidification arises from a combination of sources.

Soils vary greatly in their susceptibility to acidification (from whatever source), the degree being dependent mainly on soil buffing from ionic and mineral bases. Soils already acid are affected by additions of further acidity because the few remaining bases will be further depleted causing deficiencies of nutrients like calcium and magnesium, and developing or enhancing aluminium, manganese and other toxicities. Soils developed on readily leached, low exchange capacity (i.e. sandy) soils in humid areas are most susceptible, especially if developed from parent materials low in carbonates. This includes many of the soils of the Canadian Shield and Maritimes, and some sandy areas of southern Ontario and Quebec (Wang and Coote, 1981). Similar soils are found in parts of the central and northern Prairie Provinces, especially in the Gray Luvisolic zone. For the most part, southern prairie and B.C. soils are not very sensitive to acidity, although there are surface horizons of large areas of Alberta and west central Saskatchewan soils, including many Solonetzic soils, which are already sufficiently acid that the effects of fertilizers

and acid rain can be significant (Hoyt et al, 1981). In irrigated and heavily fertilized soils, such as those used for orchard crops in B.C., severe acidity can develop even though the soils would not otherwise have been considered sensitive. Furthermore, large areas appear to respond well to lime additions from a physical and nutritional standpoint, even though not particularly acid or sensitive to acidity development.

Another problem somewhat unique to western Canada (especially Alberta) is that of high concentrations of sulphur dioxide, and also particulate sulphur, immediately downwind of gas processing plants. Some areas of soil have become extremely acid from these deposition sources.

Trends in Soil Acidification

Nitrogen fertilizer use continues to increase generally, and with it will be a trend to greater acidification of soils to which it is applied. In sensitive soils, use of lime, or greater use of lime, will become necessary.

No real change is expected in the immediate future in atmospheric deposition rates, so the "acid rain problem", such as it is, will probably continue indefinitely.

The recognition of the acidity problem, and the potential for significant yield increases in Alberta, Saskatchewan, and the Peace River area of B.C. (Hoyt et al, 1981), may result in a viable lime marketing and distribution system in this part of the country in the next few years. This will change the seriousness of the problem markedly, as soil acidity can be corrected readily once lime is available.

SOIL CONTAMINATION

The principal concern with soil contamination is that of the persistence or accumulation of agents with the potential to damage

crop growth or quality. Examples of contaminants are heavy metals such as arsenic, lead, cadmium and mercury; and industrial compounds such as PCB. These materials find their way into soil by atmospheric dispersion and deposition, sewage sludge disposal, and industrial waste disposal. In addition, some such materials can be present in pesticides and fertilizers as either active ingredients or as contaminants. Certain biological materials can be considered, under some circumstances, to be soil contaminants. Examples include plant residues which inhibit microbiological activity, and persistent disease organisms.

The seriousness of a potential contamination problem is highly site and material dependent. For example, studies of sewage sludge at the University of Guelph show that the type of treatment process used in obtaining sludges at sewage treatment plants is as important in determining the risk of plant growth or quality damage from a contaminant as the quantity of the contaminant present in the sludge, and the effect of these processes varies from one contaminant to another (Soon and Bates, 1981). As another example, the presence of certain herbicide residues may only be of concern if particular crops are grown in the year following its use. By careful crop rotation, and good management practices, farmers can avoid most temporary soil contamination problems. Contamination by heavy metals, on the other hand, can leave a soil permanently affected, as these materials do not move readily at pH values common in agricultural soils and so they accumulate. Farmers considering accepting wastes for application to their soils should be cautious, and obtain guidance from provincial soils and crops specialists before any commitments are made.

Trends in Soil Contamination

The current trend appears to be for the risk of soil contamination by heavy metals and toxic compounds to be increasing. There are fewer locations within economic transport distances for industrial

and municipal wastes to be landfilled and costs are consequently rising. Agricultural land is an attractive alternative for these wastes, which sometimes contain significant fertlizer value. However, many municipalities permit wastes from small industries to enter the sewage system, and thus sewage sludges are often contaminated. There may be a trend from less stringent control of such sources because of economic conditions.

As was mentioned under the topic of acid rain, there is little likelihood of any major improvement in air quality in the near future. Some contaminants now being deposited on soils are accumulating and so the potential for future problems remains.

Pesticides today are now much less persistent than formerly, and this will reduce the risk of soils becoming contaminated. On the other hand, use will probably tend to increase, particularly with herbicides if minimum and zero tillage becomes widely accepted.

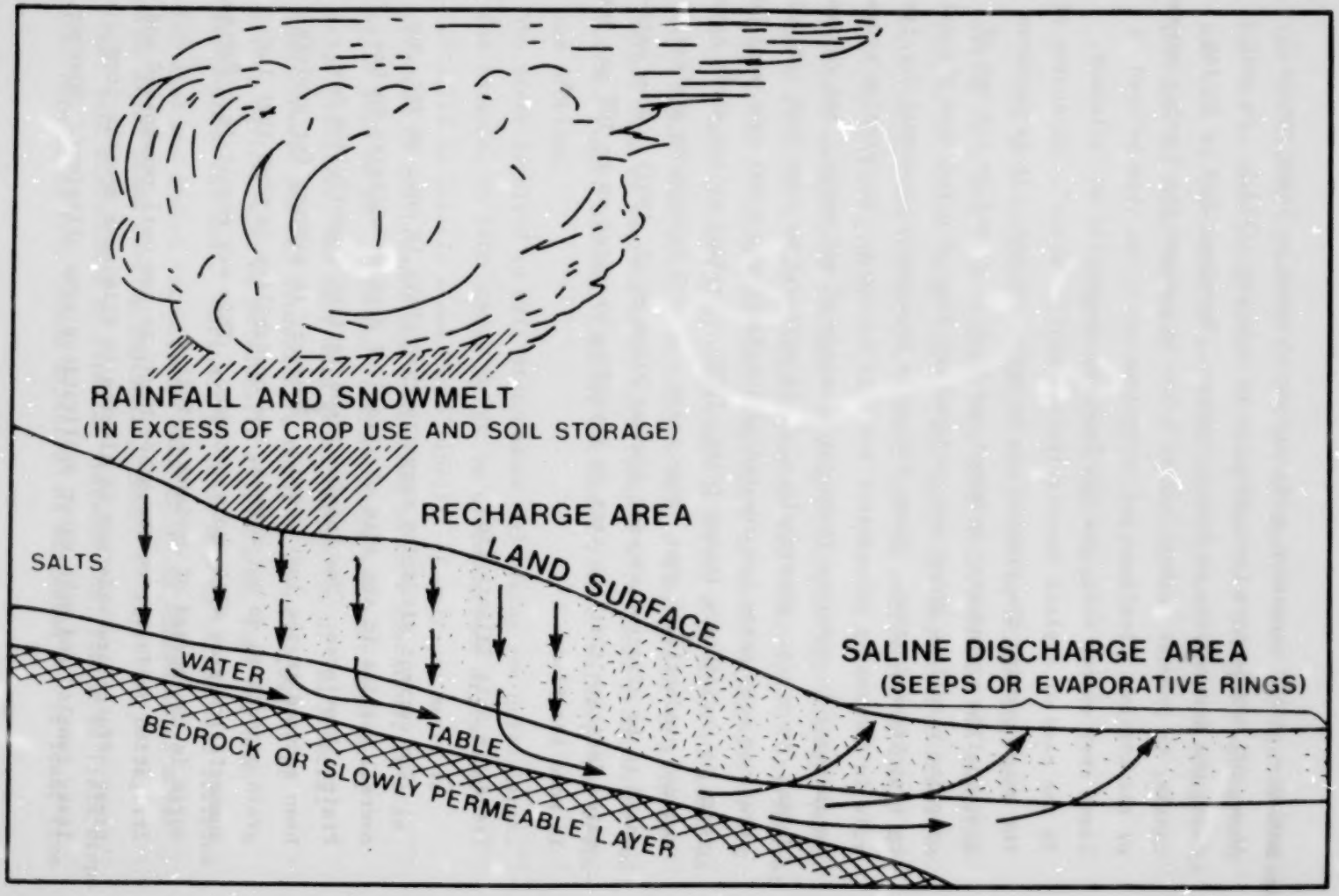
SOIL SALINIZATION

Soil salinity is a serious problem in the Prairie Provinces. It has been there in the form of salt flats and Solonetzic soils since before Europeans settled the land. The soil degradation problem currently of so much concern, however, is that of the spread of salinity into previously non-saline areas. This occurs generally as a result of a rise in the water table level, either in soils with high salt contents in the subsoil, or in soils in which the groundwater is recharged by seepage from other areas with high salt contents. Figure 3 provides a simplified view of the process of salinization (Vander Pluym et al, 1981). When the groundwater moves to the soil surface and evaporates, salts are precipitated. When the electrical conductivity of the soil (a measure of salt content) exceeds 4 milli Siemens cm^{-1}, the soil is considered mildly saline. When it reaches 14 m S cm^{-1}, no crops will grow.

The groundwater level at the discharge area may rise because of irri-

FIGURE 3.

Typical mechanism of dryland salinity development



Modified from Vander Pluym, *et al.*, 1981 (by permission of the author).

gation - either excessive applications of water or leaky canals. About 100,000 ha have been affected in this way (Ibid.). In most cases the source area is fairly evident. Measures such as lining canals, to prevent leakage, can be taken to prevent the further spread of the problem. Drainage, and irrigation water, can then be used to leach away excess salt, and the land can eventually be reclaimed.
In the case of dryland (non-irrigated) saline "seeps", the source of the water causing the problem may be quite obscure. It is believed that shallow groundwater movement has been increased by the use of cropping practices which have reduced the loss of water from the soil by evapotranspiration. Summerfallow is especially condemned for its role in increasing groundwater and salt movement. The problem seems to increase in severity following a series of wet years, then retreats during dry years. Nevertheless, it is believed by some that agriculture over many years has created an imbalance which may take many more years to equilibrate (Sommerfeldt, 1977). Dryland saline seeps have reduced productivity over large areas - over 2 million ha are estimated to be affected already (Vander Pluym et al, 1981). Some estimates indicate that the area is expanding by rates up to 10% per year in some locations.

Trends in Soil Salinization

The current situation suggests that there is not, as yet, any overall decline in the rate of spread of dryland salinity in the Prairie Provinces. One hopeful trend is that summerfallow has been reduced in the last decade. However, if markets for prairie grain production do not expand, the probability is high that the summerfallow area will again increase. This may result in a further surge in the spread of dryland salinity.
Irrigation salinity, on the other hand, is now well recognized and great efforts are underway in Alberta to eliminate seepage from leaky canals, and make water applications more efficient. However,

the continuing expansion in the use of centre-pivot irrigation systems has led to some being established on land with irregualr topography and salt in the subsoil, and these installations are resulting in an increase in local salinity.

SOIL DISTURBANCE AND MIXING

The deterioration of agricultural land by disturbance and mixing is commonly associated with such activities as the installation of pipelines (e.g. for oil and gas), drainage construction for both surface and subsurface drains, and the extraction of coal, sand etc. by surface mining.

Problems encountered include: mixing of surface and subsoil, which has a dilution effect on organic matter and other topsoil attributes; compaction of soils when heavy machinery is used, especially if the soil is wet; spreading of subsurface material over adjacent land, as for example when drain excavation spoil is disposed of in this way rather than by hauling away; interference with local groundwater and surface runoff movement causing increased risk of salinity and drainage problems.

The areas involved in soil disturbance and mixing are quite large. For example, in 1980 almost 50,000 km of subsurface drains were installed in Ontario alone (OMAF, 1981). If only one metre is affected by disturbance and compaction in this operation, this is still 5000 ha yr^{-1}. In the prairies there are over 5000 km of major pipelines, and many more km of feeder lines. In Alberta, Saskatchewan and New Brunswick, a total of about 12,000 ha of either agricultural or potentially agricultural land has been strip-mined for coal. Nationally, about 85,000 ha has been stripped for sand and gravel extraction - much of it in agricultural areas near major urban centres (Marshall, 1982).

After soil disturbance by pipeline installation, yields of field crops like corn in eastern Canada appear to be depressed for at least five

years (Culley et al, 1982). For some crops, and in many dry-region soils, yields are hardly affected at all. When reclamation is attempted for land that has been strip mined, many years may be needed before crop yields return to pre-mining levels.

Trends in Soil Disturbance and Mixing

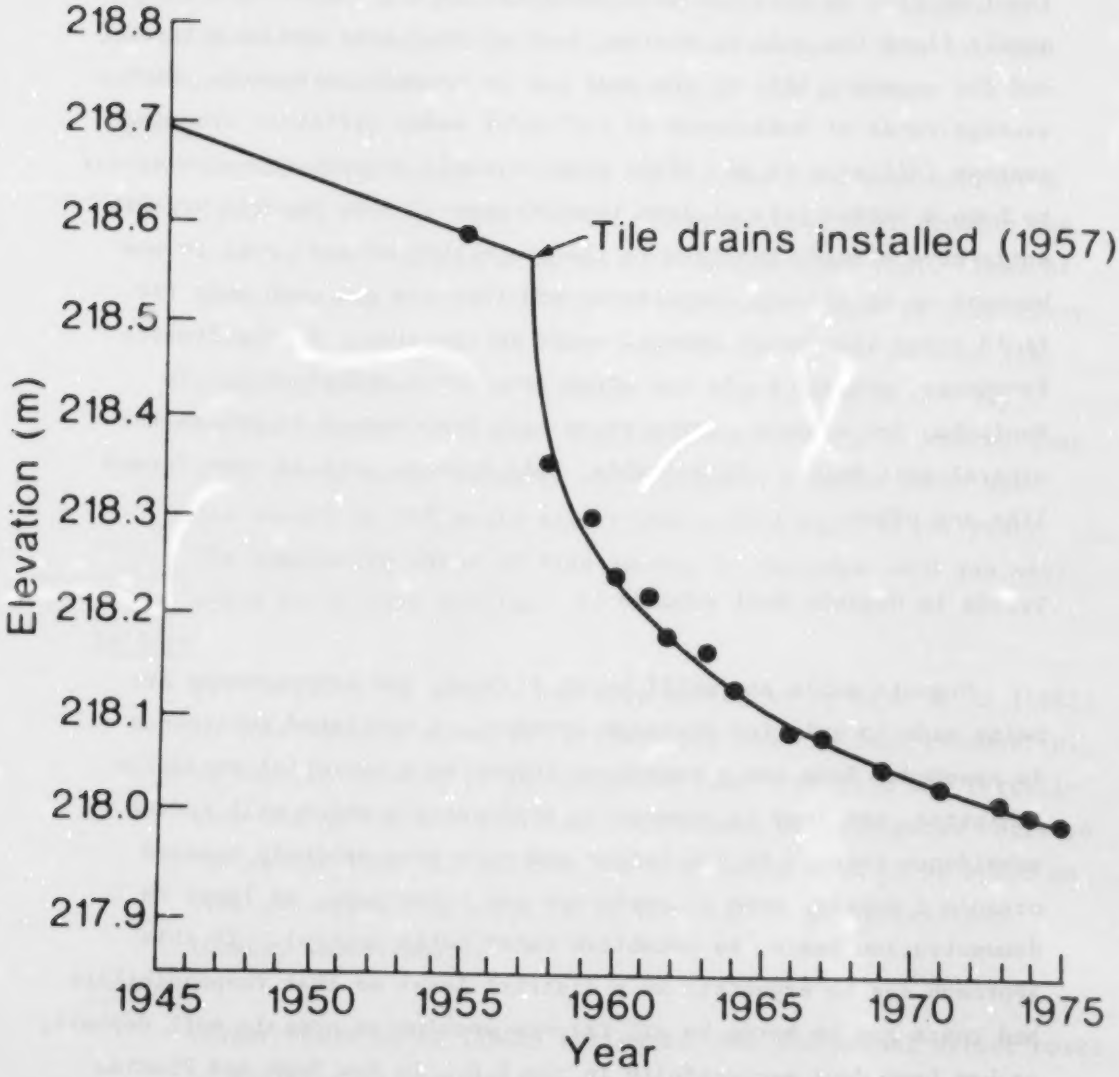
There is a strong probability that pipeline construction will continue, and an area in which much activity is likely to occur is eastern Canada, especially Quebec and the Atlantic Provinces. This is unfortunate for soil quality, as these soils are those most likely to be disturbed when wet, and serious structure damage occurs under these conditions. Similarly, drainage is likely to continue, with the wetter Atlantic areas suffering a certain amount of soil deterioration in the process particularly from construction of large surface outlet ditches. Clearly, however, the drainage benefits outweight the losses. Drainage is also increasing rapidly in the irrigated areas of Alberta for salinity control.
Surface mining, especially for coal, sand and gravel, will certainly continue in agricultural areas. One estimate indicates that in 25 years time, over 5000 ha of agricultural land in Alberta will be surface mined for coal each year (Hermans and Goettel, 1980). It is hoped that legislated reclamation work will mitigate, somewhat, the effects of this disturbance.

SUBSIDENCE OF ORGANIC SOILS

Organic soils are a valuable resource which, in those parts of the country with suitable climatic conditions, are of great significance for specialty crop production such as vegetables. Unfortunately, when organic soils are drained, as they must be for crop production, they begin to subside as a result of oxidation, shrinkage, loss of buoyancy, compaction and erosion. Figure 4 shows the effect

FIGURE 4.

Observed organic soil subsidence at Holland Marsh, Ontario



Reproduced from Irwin, 1976
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of drainage improvements on the subsidence of an Ontario organic soil. Immediately following drainage improvements in 1957, the rate of subsidence, which had previously settled down to about 1.1 cm yr^{-1}, increased to over 20 cm in the first year. Only after 10 years did the rate return to that prior to the drainage improvements (Irwin, 1976).

If proper water table controls are instituted to maintain the water level as high as possible when machinery is off the soil, and to nearly flood the soil in winter, much of this loss can be delayed, and the economic life of the soil can be greatly increased. With average rates of subsidence of 1-7 cm/yr under different cropping systems (Millette et al, 1982) many valuable organic deposits appear to have a useful life of less than 50 years. Some Ontario organic soils have already subsided to the stage that mineral soil is now brought up by tillage operations, and they are now used only for field crops like other mineral soils in the area. In the Prairie Provinces, organic soils are often considered undesirable. In Manitoba, for example, large areas have been burned to expose the mineral soil below. If suitable, this mineral soil is then farmed like any other.

Trends in Organic Soil Subsidence

Organic soils are still being drained, and improvements are being made to existing drainage systems, so continued subsidence is assured. Some new research on copper as a microbial oxidation inhibitor may lead to commercial applications which will reduce subsidence rates. In the larger and more progressively managed organic deposits, some attempts are now being made, at least on a demonstration basis, to establish water table control. If this approach can be organized at a district level so that responsibility and costs can be borne by all farmers working an organic soil deposit, as has been done successfully in the U.S., in New York and Florida

for example, the rates of subsidence can probably be reduced significantly.

ECONOMIC IMPLICATIONS OF SOIL DEGRADATION

Some estimates have been made of the economic losses which agriculture is suffering as a result of different types of soil degradation. They are generally based on very broad assumptions, and so should be treated with caution. Nevertheless, they provide an interesting perspective on the severity of the problem:

Erosion

- In Ontario, a county by county survey has just been completed (Wall and Driver, 1982) which estimated that soil erosion was costing the Province's farmers $74 million per year. Loss of production accounted for 37% of this total, loss of fertilizer nutrients a further 41%, and loss of pesticides another 11%. Clearing sediment from drainage ditches accounted for 9%.
- In the Prairie Provinces, the PFRA has recently estimated that soil conservation measures which reduced erosion (both wind and water) by 50% would save farmers $2.8 million per year. The cumulative value of this saving to the year 2000 was estimated to be $271 million.

Acidity

- Soil acidity in Alberta has been estimated by Hoyt et al (1981) to cost farmers about $85 million per year in lost production.
- In eastern Canada, it is estimated that acid rain and fertilizers add to the overall lime requirement of cultivated soils to the extent that $12 million per year would need to be spend on lime and spreading costs if it were all to be neutralized (Coote, unpublished).

Salinity

- Vander Pluym et al (1981) estimated that the annual direct costs of salinity to prairie farmers in lost production was $15

million in irrigated areas, $16 million in rangeland, and $51.5 million in dryland field crops. He also estimated that the indirect loss to the prairie economy amounts to over $100 million per year.

- The PFRA (1982) study estimated that if the spread of soil salinity could be arrested, farmers would save nearly $26 million per year. The cumulative value of this saving to the year 2000 would be $2,479 million.

CONCLUSION

Soil degradation in Canada is now a recognized fact of life for farmers and agricultural specialists. It is now receiving a great deal of attention - much as the environment did ten years ago. Hopefully we won't overreact by establishing vast new bureaucracies to deal with it!

Agriculture Canada's Land Resource Research Institute has a Resource Protection project, and a Soil Degradation Working Group of the Soil Survey, which are working together to improve mapping and risk assessment for soil degradation. This program includes research to support interpretations of soil data for risk assessment. All of the Research Stations with soils expertise are involved in some aspect of research on soil degradation problems common in their region. So also are all of the Universities with Soil Science departments. On the prairies, the new Soil Conservation Division of the PFRA is planning to work on information dissemination, control measures and incentives programs to reduce soil degradation.

At the provincial level, all Ministries of Agriculture are aware of the problem, and are anxious for information with which to plan extension and incentives programs. They are supported by a variety of Conservation Districts or Authorities which are partly run by farmers, and which can run demonstration projects and assist their members and neighbouring farmers. These provincial Ministries are already playing a leading role in interpreting research results and designing and implementing remedial strategies.

Most recently, the Canadian Federation of Agriculture has taken the initiative and prepared a policy paper on soil degradation, following a workshop on this topic in Ottawa in December 1982. The lobbying of this group will, hopefully, help to increase the priority and funding level of soil degradation related work, so we can all get on with the job of developing controls and showing farmers how and where to implement them.

BIBLIOGRAPHY

Bisal, F. and J. Hsieh. 1966. Influence of moisture on erodibility of soil by wind. Soil Sci. 102 (3): 143-146.

Coote, D.R. and J.F. Ramsey. 1983. Quantification of the effects of over 35 years of intensive cultivation on four soils. Can. Jour. Soil Sci. 63 (1): (in press).

Coote, D.R., J.F. Ramsey and J. Dumanski. 1981 a. An assessment of the degradation of agricultural lands in Canada. Res. Br., Agric. Canada, Ottawa, Ont.

Coote, D.R., D. Siminovitch, S.S. Singh and C. Wang. 1981 b. The significance of acid rain to agriculture in eastern Canada. Res. Br., Agric. Canada, Ottawa, Ont.

Coote, D.R. (unpublished). Wind erosion risk assessment for the Prairies - preliminary draft. Land Resource Research Institute, Agric. Canada, Ottawa, Ont.

Coote, D.R. (unpublished). Land degradation data prepared for UNESCO Survey, 1982. Land Resource Research Institute, Agric. Canada, Ottawa, Ont.

Culley, J.L.B., B.K. Dow, E.W. Presant, and A.J. McLean. 1982. Recovery of productivity of Ontario soils disturbed by an oil pipeline installation. Can. Jour. Soil Sci., 62: 267-279.

De Jong, E., H. Villar and J.R. Bettany. 1982. Preliminary investigations on the use of ^{137}Cs to estimated erosion in Saskatchewan. Can. Jour. Soil Sci., 62 (4): 673-684.

Dubé, A. 1975. L'eau et l'érosion des sols. Ressources. 6(4): 8-15.

Hermans, J.C. and A.W. Goettel. 1980. The impact of surface mining on agriculture in Alberta. Proc. Symp. Adequate Reclamation of Mined Lands? Soil Cons. Soc. Am., March 26-27, Billings, Montana. pp. 11.1-11.10.

Himelman, D. and N.E. Stewart. 1979. Soil erosion studies in Prince Edward Island. Proc. Soil Erosion Workshop, Nova Scotia Agric. Coll., Truro, N.S. April 17-19. pp. 37-43.

Hoyt, P.B., M. Nyborg and H. Ukrainetz. 1981. Degradation by acidification. Proc. 18th Ann. Alberta Soil Science Workshop. Agricultural Land, Our Disappearing Heritage. Feb. 24-25, Edmonton, Alta. pp. 41-71.

Jenkins, G.C. 1982. What cost erosion? Unpublished paper, Manitoba Dept. of Agric., Winnipeg, Man.

Irwin, R.W. 1976. Soil subsidence of the Holland marsh. Engineering Tech. Pub. 126-34. School of Engr., U. of Guelph, Guelph, Ont.

Ketcheson, J.W. and L.R. Webber. 1978. Effects of Soil Erosion on Yield of Corn. Can. Jour. Soil Sci. 55: 73-75.

Marshall, I.B. 1982. Mining, land-use and the environment: I. A Canadian overview. Land Use in Canada Series, No. 22, Lands Dir., Environ. Canada, Ottawa, Ontario.

McGill, W.B., C.A. Campbell, J.F. Dormaar, E.A. Paul and D.W. Anderson. 1981. Soil organic matter losses. Proc. 18th Ann. Alberta Soil Science Workshop. Agricultural Land, Our Disappearing Heritage. Feb. 24-25. Edmonton, Alberta, pp. 72-133.

Millette, J.A., B. Vigier and R.S. Broughton. 1982. An evaluation of the drainage and subsidence of some organic soils in Quebec. Can. Agr. Eng. 24 (1): 5-10.

Ontario Ministry of Agriculture and Food (OMAF). 1981. Tile drainage statistics within the Province of Ontario. Capital Improvements Branch, Toronto, Ont.

Prairie Farm Rehabilitation Administration (PFRA). 1982. Land degradation and soil conservation issues on the Canadian Prairies, an overview. Dept. of Reg. Econ. Expan., Regina, Saskatchewan.

Reid, J.B. and M.J. Goss. 1981. Effect of living roots of different plant species on the aggregate stability of two arable soils. Jour. Soil Sci. 32: 521-541.

Ripley, P.O., W. Kalbfleisch, S.J. Bourget and D.J. Cooper. 1961. Soil erosion by water. Agric. Canada pub. 1083.

Sommerfeldt, T.G. 1977. The lull before the storm. Proc. Alberta Dryland Salinity Committee. Dryland Salinity and Seepage in Alberta. Alberta Agric., Edmonton, Alberta, pp. 1-4.

Soon, Y.K. and T.E. Bates. 1981. Land disposal of sewage sludge. Report of projects 72-5-17 and 78-012-31, University of Guelph, for Ontario Ministry of the Envrionment, Toronto, Ont.

Stewart, N.E. 1976. Erosion of agricultural lands in the Maritime Provinces. Report for A.P.A.S.C.C. Task Force on Soils, Dept. of Agric. and Forestry, Charlottetown, P.E.I.

Toogood, J.A. 1963. Water erosion in Alberta. Jour. Soil and Water Cons. 18: 238-240.

Vander Pluym, H.S.A., B. Patterson and H.M. Holm. 1981. Degradation by salinization. Proc. 18th Ann. Alberta Soil Sci. Workshop. Agricultural Land, Our Disappearing Heritage. Edmonton, Alberta, Feb. 24-25. pp. 9-40.

Van Vliet, L.J.P. and G.J. Wall. 1981. Soil erosion losses from winter runoff in southern Ontario. Can. Jour. Soil Sci. 61: 451-454.

Wang, C. and D.R. Coote. Sensitivity classification of agricultural land to long-term acid precipitation in eastern Canada. Res. Br., Agric. Canada. Ottawa, Ontario.

Wall, G.J. and G. Driver. 1982. Cropland soil erosion, estimated cost to agriculture in Ontario. Report of the Ontario Inst. of Ped. and Ont. Min. Agric. and Food, Guelph and Toronto, Ont.

Wischmeier, W.H. and D.D. Smith. 1965. Predicting rainfall - erosion losses from cropland east of the Rocky Mountains. USDA Agric. Handbook No. 282.

Woodruff, N.P. and F.H. Siddoway. 1965. A wind erosion equation. Proc. Soil Sci. Soc. Am. 29: 602-608.

FORESTRY AND SOIL PRODUCTIVITY IN BRITISH COLUMBIA

W. Young, Chief Forester
Ministry of Forests, B.C.

We have come a long way, indeed, when a forester delivers one of the keynote speeches at a meeting of soils scientists.

It wasn't so long ago that foresters thought soils analysis was a waste of time, and that a pedologist was either a foot doctor or the polite name for a sex pervert.

It also wasn't so long ago that pedologists in this province concentrated virtually all of their efforts on agricultural matters.

That is certainly not the case today. Foresters know they desperately need the knowledge and advice of soil scientists. And pedologists recognize the massive challenge that waits for them in British Columbia's forests.

It is estimated that this province has 47 million hectares of productive forest land. That's why, for decades, British Columbians thought the forest would go on forever. But of that 47 million hectares, only seven per cent is classified as "good" forest site.

It is on this most productive land that the practice of intensive forestry pays the biggest dividends. However, the pressure to divert this good site land to non-forest uses has been growing, year by year.

Agriculture is one competing use. But much of the seven per cent is situated near cities and towns, so settlement -- which also threatens farm land -- threatens the best forest land too. There are any number of other users competing for this land as well. But that is a whole other speech.

The point I want to make to <u>this</u> distinguished group is: we need every bit of forest land we have, to meet the demands put upon it by society -- not the least of which is to supply timber to meet the needs of industry.

That means we cannot afford to see significant pieces of the forest land base blow away in the wind, slide into creeks or be destroyed in other ways.

Even in these lean times the forest is British Columbia's most valuable resource and the forest industry is the king-pin of our economy. That's why part of the Ministry of Forests' mandate is to manage the timber harvest and

foster a healthy forest industry.

And inevitably, industrial operations mean some disruption to the stability and productive capability of the forest soils.

Nowhere else in the world does the terrain pose such difficult problems for loggers. . .and for foresters. . .and now, for soil scientists. I intend to examine some of these problems, and tell you how our ministry and the forest industry are dealing with them.

Before I begin, I feel I should issue a disclaimer. I am not technically competent to discuss the esoteric details of your specialties. You'll have to put up with a layman's point of view.

Also, I've chosen not to mention the potential for soil degradation through nutrient losses by successive croppings. In the long term, this can be a threat in forestry as it is in agriculture. But with harvests on a site occurring every 50-80 years, rather than annually, the immediate concern is not so critical. Nevertheless, we have undertaken some research on this matter and while nutrient loss through the first harvesting operation is not significant, this research did lead to some change in practices to address this matter and to conserve productivity.

Today, then, I'm going to talk about soil degradation in forestry and today's concerns.

I will be using a number of slides to illustrate some points. We're told that a picture is worth a thousand words. If that's accurate, these slides are going to save me about 22 thousand words. And I'd estimate conservatively that this will spare you having to listen to an extra two and a half hours of me talking! You have much to be thankful for!

Let us return to the point I made a moment ago: industrial and other forest operations automatically mean some soil disturbance.

Some man-made disturbance can be tolerated. Some is even necessary to carry out our resource management programs. But much must be prevented, or if not prevented, cured.

What are the greatest soil management problems we face every day in the forest?

There is the soil degradation caused by fire. Not all of it can be blamed on wildfire. Badly-managed slash-burning and other controlled burns

can also sear the nutrients out of the soil, diminishing or even destroying the chance for re-establishing productive forest.

We must deal with soil compaction and nutrient depletion, particularly on logging show landings. These landings add up to a fair chunk of forest land which, unless rehabilitated, can be considered lost from the productive land base.

But the greatest threat is erosion -- soil loss. . . mass wasting caused by harvesting unstable slopes . . . surface erosion leading to gully erosion. And of all the causes of erosion, the single most important is in the construction of forest roads rather than the logging operation itself.

I intend to discuss this problem at some length.

Building a roadway through forest can impair soil stability, damage fish habitat and watersheds, and be responsible for a great deal of visual degradation.

In addition, there is the likelihood of soil disturbances outside the actual right-of-way but associated with the road -- slides and gullies on logged slopes. . .skid trails on clearcuts. . .landings.

It's estimated that one kilometre of newly constructed forest road in steeper areas will have from one-half to three hectares of exposed soil and surficial material. As protective plant cover is removed, the exposed soil is often left unprotected on steep cut-and-fill slopes. These raw slopes become extremely vulnerable to erosion by wind, water and frost.

The sediment produced by these eroding road slopes may not only degrade water quality in streams, but may also undermine the road itself.

Although surface erosion is not as obvious or spectacular as mass wasting, it's a serious problem and can move a great deal of soil material over the lifetime of a road system.

This is what can happen. That doesn't mean it must happen. There is a lot we can do, and are doing, to mitigate the effects of road construction.

Possibly the most important requirement for dealing with this challenge is foresight -- anticipating the problem and planning ahead. That means identifying sensitive sites in advance, studying the geotechnic factors, and improving our engineering design and drainage structures for the new road.

Once the road is completed, we have to move quickly to prevent surface erosion in the potential problem areas. We have found that the most economical and effective means of controlling surface erosion is through revegetation procedures -- in plain words, planting grass . . .or more accurately, a grass-legume mix. Both the forest industry and the Ministry are involved in this program in high priority problem areas - such as the Queen Charlotte Islands.

We use a direct or dry seeding method on slopes not exceeding 27 per cent of steepness. For steeper slopes, we switch to hydroseeding. It's more costly than dry seeding, but also more effective.

In a few minutes I'll show you some slides of this procedure; I think you'll be impressed at the results we are getting in a relatively short period.

On slopes where seeding with the grass-legume mix is not entirely effective in controlling surface erosion, we establish shrub and tree species.

These methods prove useful on cut-and-fill slopes, slides and gullies. Furthermore, timely applications can stop surface erosion from escalating into mass wasting -- for instance, rills developing into gullies and undermining the slope.

The tools for revegetation range from a simple cyclone seeder to the more sophisticated hydraulic slurry applicators. We are also using aerial seeding of mountain slopes not accessible to ground-based equipment. The ministry has been working on designing an improved version of an aerial hydroseeder to treat steep gully slopes. And we've had considerable success with dry-seeding from helicopters.

This extensive rehabilitation program did not spring up overnight. It grew out of a roadside revegetation research project begun by the Ministry of Forests on a modest scale almost eight years ago. We have come a long way since then.

And now, I promised you some pictures. . .

OVERHEADS

I'm particularly keen to show you these first two slides, because the action takes place very close to this hotel.

1. This is a Ministry of Forests Research Branch experimental hydroseeder, working on a grade on the Harrison East Road.
2. And here is the same site, one year later. Green is my favorite color.
3. Commercial hydroseeding equipment is also available. This 15-hundred-gallon machine is owned by Terosol Limited of North Vancouver.
4. This machine is twice as big -- three thousand gallons. And again it's owned by Terosol. A rig like this can handle jobs of any size . . . provided they're accessible.
5. For less accessible areas, we use hydroseeding buckets.
6. This is a road failure in the Queen Charlotte Islands.
7. And here it is again, one year after hydroseeding. Again, the forest industry in the Queen Charlotte Islands are now involved in this process in an operational way.
8. Let's switch to another kind of soil problem -- landing sites in the Interior dry belt fir zone. After logging, these sites suffer severe compaction. In this case the landing was deep-ripped and dry-seeded with a grass-legume mix.
9. Look at the response only three months after treatment. The nitrogen-fixing legumes are well-established.
10. Still on the same landing. . .this is what happens when we plant a perfectly good seedling on the untreated site.
11. And this is a similar seedling on the treated site. Some difference!
12. I mentioned that for severe erosion problems, native shrubs are being used in conjunction with hydroseeding. This is one of four shrub propagation centres established for this purpose.
13. Here the shrubs are being planted in the field.
14. And here is a ministry publication that has proved so popular, it's in its second printing.

END OVERHEADS

Among those slides you got a couple of glimpses of the Queen Charlotte Islands, but not the steep slopes for which that area is famous. . .or infamous.

I'm sure you all remember the Riley Creek fiasco in the Queen Charlottes four years ago. What a free-for-all that was!

Now, four years down the road, I'm happy to report that: the salmon are still in Riley Creek . . .the logging area that caused all the furor has a flourishing three-year-old plantation. . .and the slide area and forest road have been effectively hydro-seeded.

Also four years down the road, we have seriously come to grips with the problems of site rehabilitation following steep-slope logging. You've seen some seeding operations, now let's look at some techniques of mechanical site preparation for planting where soil disturbance is required but designed to minimize erosion.

OVERHEADS

Since mechanical site preparation on steep slopes carries the potential of creating erosion channels, where possible the treatment is carried out along the contour.

15.-16. These first two slides show one type of machine which is used to prepare planting trails along the land contour. This is an F.M.C. 220C, equipped with what is called a six-way brush-type blade.

17. This shows the results produced by this machine. Note that it is working along the contour.

18. Here is some more work done by the 220C -- a planting trail along a contour with a 45-per-cent side slope.

If the slope is very steep, it is not possible to follow the contour and, in these situations, an intermittent type of site treatment can be carried out. This may be done with a crawler-type machine, of the type you've just seen, using what's called a dip-and-dive technique. That's where the machine works straight down the slope, alternately lowering and lifting its blade. This leaves cleared patches with a mound at the lower

edge, which prevents surface water flow and provides an excellent planting spot for a seedling.

19. Here you see just such a clearing and mound.

20. There are also machines designed to work intermittently and one of these is the Leno scarifier. This is a Leno attached to a J.D.640 skidder, working on a 55-per-cent slope. That's enough to turn your hair gray!

21. And this is the result of that treatment.

END OVERHEADS

Mechanical site preparation in sensitive areas will always be something of a trade-off -- how much good are we doing and how much soil damage must we cause in order to do it? But techniques such as those you've just seen . . .and a new generation of versatile machinery. . . will go a long way towards addressing the problem.

Of course there are other options in preparing a site for reforestation including prescribed burns.

The ministry is involved in a number of programs which may be only indirectly connected to the issue of soil degradation, but which can be expected to produce data of direct interest to the forest pedologist.

One such program is the Fish-Forestry Interaction Program, which is studying streams and the hillsides above them on -- where else? -- the Queen Charlotte Islands.

This is a project that grew directly out of the Riley Creek incident. It involves the provincial Ministries of Forests and Environment and the federal Departments of Environment and Fisheries and Oceans. In addition, the Queen Charlotte Island-based forest industry is involved through the Forest Engineering Research Institute of Canada (FERIC).

The research program is aimed at learning more about the problem of landslides. . .their effect on forest land and fish habitat. . .ways of reducing landslides . . . alternate logging methods for steep slopes. . . and ways to restore and improve the productivity of both forest land and fish habitat.

Unlike studies dealing with a single stream, this program is studying the complete range of watersheds found on the Charlottes, and will cover the major problems caused by slides on those islands.

The information generated will be the most extensive available on the subject, for any area of the B.C. coast.

Not so extensive but far more detailed is the Carnation Creek Experimental Watershed Project on Vancouver Island.

That project was started 13 years ago, to study the effects of streamside logging and post-logging treatments, and it is also providing soils information of considerable value.

However, the best source of technical information for the forest pedologist in B.C.. . .and a most useful source of information for the forester. . .is the Ministry of Forests' province-wide Ecology and Soils Program.

This program has three main thrusts -- research, training and ecosystem classification. Others far more competent than myself will be talking about our research, so I'll stick to the other two aspects.

We are pardonably proud of what we have managed to accomplish so far in our Ecosystem Classification Program.

The most obvious benefit of the program has been the development of what we call the Ecosystem Framework, which allows Ministry and Industry foresters to readily identify a forest ecosystem, and then -- based on past experience in similar ecosystems -- to predict the effects of a particular management prescription.

With the aid of the Ecosystem Framework, foresters can make management decisions for both the present and the future, based on field experiences, research results and other available knowledge. It is an extremely valuable tool.

Also as a direct result of the Ecosystem Classification Program, a wealth of information has been published by the ministry over the past few years.

At this time, biogeoclimatic maps are available for three-quarters of the province, and others are nearing completion. We also have operational

reports -- published or in draft form -- for about a third of the province, and others are being prepared covering another third.

OVERHEAD

22. Here you can see the significant progress we have made in our classification system. It is a massive undertaking.

END OVERHEAD

But just having the information available isn't enough. We have to put it to use. And so we have been making, and continue to make, a major commitment to the training of operational staff, both within the ministry and in industry.

I believe I can safely say the ecological awareness of the Ministry's and Industry's operational staff has greatly increased in a comparatively short period of time.

For example, Ministry of Forests' staff alone are spending a total of eight to ten man-years, every year, in field and office courses in ecosystem identification -- including basic courses in soils -- learning how to use new tools and new information to better manage our forest and range lands.

I can't estimate the forest industry's investment in this type of training, but it is also considerable.

One of the spin-off benefits of the Ecology and Soils Program is that we can get an overview of the serious soil-problem areas in the province. I'm talking about those lands that fall into the E.P.A. category, Es.

Just in case there are any other poor laymen in the crowd, the Es category identifies ecosystems having fragile or unstable soils that may be subject to unacceptable deterioration following forest harvesting activities.

I'm talking about actual or potential soil problems such as surface erosion or mass movement. It might interest you to know that approximately 10 per cent of the productive forest land in the province is designated with an Es. In some areas it is approaching 20 per cent, while in others the potential problem is relatively insignificant.

This and similar soil stability information is invaluable to me in carrying out one of my legislative responsibilities as Chief Forester of this province--setting down the forest land base for matters such as soil stability before setting the rate of harvest in our Timber Supply Areas. Only with a good data base can we make good decisions.

It's not just me. Professional foresters throughout the province are looking to the professional pedologists to provide the soils information they need to make good decisions about forest management.

Right now, as you meet in Harrison, the Association of B.C. Professional Foresters is holding its annual meeting in Kamloops. In fact, I have to leave your meeting today to attend.

If I have time, I may stop off and renew my roots at my birthplace --just north of Spuzzum. Don't laugh, it isn't every person who can say that his mother used to take him to Spuzzum for Saturday night shopping.

I firmly believe pedologists and foresters have much of interest to say to each other. One day, perhaps, we can have such dialogue at a joint annual meeting. When that happens, it will be a great day for both groups of resource professionals...and, more important, for the resource itself.

Thank you.

SOIL DEGRADATION AND B. C. AGRICULTURE

Dr. G. A. MacEachern
A/Deputy Minister
B. C. Ministry of Agriculture and Food

INTRODUCTION

This is an important workshop. Soil degradation is an important subject to the British Columbia agricultural community and to the future welfare of the people of this province and beyond.

I am not a British Columbia soils expert so you are not getting a definitive address on "Soil Degradation in Agriculture in British Columbia" as stated in the program. I'm here primarily to listen and learn and you don't hear an economist say that and mean it very often. I do want to become better aware of the degradation problems and ideas about how these may be effectively addressed.

SOIL DEGRADATION IN B. C. AGRICULTURE: AN OVERVIEW

Clearly the loss or potential loss of the agricultural land resource or the productive soil resource has been and is a serious concern to the agricultural development of this province. British Columbia has taken innovative steps leading the way in many respects in preserving the agricultural land resource from urban sprawl through the establishment of the agricultural land reserve.

There are other important dimensions of the agricultural land resource question that have and are being addressed by the British Columbia Ministry of Agriculture and Food, such as land development and improvement, range improvement wetland development, organic soil improvement and other land improvements. Considerable extension efforts have been and are undertaken with respect to management improvements related to land use and farm productivity. However, there is still a growing concern with soil degradation, i.e. the deterioration of some of the most productive agricultural lands through loss of topsoil, decline in organic matter,

deterioration in physical structure (composition), chemical and nutritional imbalances. Soil erosion in the Peace River region is widespread. Some upland soils in the Lower Fraser Valley represent a severe erosion hazard, and there are drainage and soil compaction problems in evidence. Acidification of substantial acreages of British Columbia orchard lands is worrisome. There are other problem areas - which others are addressing here at this conference.

The loss or potential losses to the agricultural resource, the need for productive agricultural land for agricultural development and production improvement has elicited direct or indirect responses and actions to these concerns by many groups and individuals. In some cases substantial private and public resources in money and manpower have been devoted.

QUESTIONS RAISED

The impression one gets from some of the recent literature on the subject, including the recent Canadian Federation of Agriculture report on their Soil Conservation Workshop, December 8 - 9, 1983 in Ottawa (which unfortunately no one from British Columbia was able to attend), and from those planning this meeting is that the public response to date has been inadequate and that corrective action to address soil degradation is a low government priority. The general feeling expressed by a good many soil scientists and some officials is that government soil conservation programs tend to end up on the bottom of the priority list - that budgets are quite small compared to price and income assistance types of government support programs to agriculture. Voluntary efforts have not met with much success and conservation techniques are costly with only long term benefits so farmers continue mining the soil.

Technology, increasingly being used in modern agriculture, is often considered part of the villain and is felt not to be neutral with respect to soil quality. The feeling is that some of the technology is creating a false sense of security that really threatens future food security due to degradation effects. It is also suggested that laws or legislation is the answer, but that governments are reluctant to pass and enforce laws with teeth. Others suggest supportive legislation to facilitate voluntary co-ordinative mechanisms. While still others suggest that the experience

with co-ordinative-participative mechanisms are open to serious question as to effectiveness. No doubt the choices or most effective mechanisms depend on whether we are talking about private land, externalities or public property.

What's Needed

Greater efforts to create public awareness is an important step, but in my view it is not sufficient. From the current discussion - debate one senses considerable frustration and can come away feeling quite frustrated at not being able to find significant areas of agreement to reach conclusions. This may be due in part to recognition of the complex dynamic aspects of those problems but not sufficiently defined to allow official understanding of the importance of soil degradation or consideration of effective courses of action to address these problems. I don't have the answer and share some of your frustration. Perhaps we are not unlike a great many farmers - we realize a problem exists, has existed for some time. We are not sure it will forever intensity in the future. Linear extrapolation is inappropriate for providing realistic future scenarios. We are not sure the soil degradation problem will ever go away even with substantial public investment or whether we would want it to.

What appears evident from the discussion to date is that better data, better problem definition is needed particularly an improved framework which depicts the dynamics and inter-relationships of soil degradation problems, i.e. a systems approach. When it comes time to develop proposed courses of action, effective policies and programs, there would also appear to be real benefits from involving multi-disciplines.

Considerable progress continues to be made in understanding complexities, inter-relationships and the dynamics of the agriculture and food production - consumption system and its relationship to the capital stock i.e. the soil or land resource. This awakening is relatively new. Until recently the focus has almost exclusively been on the production-consumption aspects including agriculture - food policy. This has meant attention to current inputs, outputs and attendent support to financial programs impacting on factor and product prices and flows.

In short, a dominant "through-put" focus ignoring the capital stock: the land resource. The capital stock is important in generating the flows and net worth values are affected by its use. The capital stock concept applied to the agricultural soil resource means that the status of the soil resource can be reflected in normal social and business accounting systems. The growing practice of including the capital stock (the soil resource) with the conventional through-put model (production-consumption) can mean real progress in thinking about profitable farm practices, agricultural development, agricultural policies and programs that take proper account of the soil resource (all costs and returns) to focus on realizing a true optimum.

Equally important, in recent years, has been the refinements made in systems analysis, cost- benefit analysis - how to handle long timeframes - future uncertainty and risk. We are now better able to think in terms of optimum decisions for the present and future, not settle for maximum or minimum criterion or standards as best. The "best" practice is seldom the optimum all around.

This kind of integrated thinking and analysis, even though one can seldom obtain all the detailed data desired, has real utility in dealing with soil degradation problems and solutions.

<u>One brief example</u>: Recently, Dr. Walker, of the University of Idaho, published a report dealing with a systems analysis of soil conserving practices vs. conventional practices on soils principally in Washington State experiencing various degrees of erosion. In co-operation with soil scientists and others he developed a soil erosion damage function for various sites experiencing differing rates of productivity and yield decline caused by accumulative soil loss and degradation. The conserving practices (technology) costs were also examined. One of the objectives was to determine over a future time horizon the optimum time to adopt conservation practices. The results generally conformed with what some farmers were doing on similar sites. In some situations, the optimum adaption was now, in 5 years and in some cases, well in the future. The same model also served to assess the importance of different variables to speed conservation or the most important factors influencing the optimum decision. Dr. Walker found the following factors important:

- the cost of the conserving practices (can the conserving practices sustain conventional yield levels)

- the discount rate (interest rates - the lower the rate the faster the pay-back)
- high product prices (particularly if felt to be short lived, encouraged continued mining of the soil in the short term, but raised the demand for and benefits from conserving technology, much quicker in the longer term)

There are many implications from this kind of research. For example, observed behavioural patterns offarmers may not be inconsistent with optimum decision making re soil conservation. A great many factors can impact the adoption of soil conserving technology which suggest it can be induced.

CONCLUSION

Soil degradation is an important concern to British Columbia agriculture and its future development. The British Columbia Ministry of Agriculture and Food is addressing some important dimensions of soil degradation and related land resource questions. There has been some expressions that the public response to date is inadequate - that soil degradation problems are a low government priority and that this needs to be corrected. There appears a strong likelihood for continued frustration by advocates until better problem definition, more realistic frameworks depicting this complex, dynamic problem are applied. Considerable progress has been made in developing tools to help understand the dynamic inter-relationship of the problems involved and greater efforts in applying these models could help clarify problems and assess policies and programs to effectively adress them.

We can be reasonably optimistic about future progress if better information and improved knowledge is developed about the problems and greater efforts are devoted to such things as meeting the increasing demand for soil conservation technology by developing and demonstrating easily adoptable and profitable conserving practices and systems. The success achieved in such efforts will greatly assist this province in achieving optimum expansion of agricultural food production consistent with good stewardship of our critical agricultural land and water resources - the critical capital stock.

DEGRADATION EFFECTS OF SOIL EROSION BY WATER AND WIND

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This paper discusses the causes and effects of soil surface erosion by water and wind, assesses the extent thereof in B.C., and examines some soil conservation practices. Other types of erosion, such as gully erosion due to slope instability, stream bank erosion, and mass-wasting are not considered. The latter is considered in another paper in these proceedings.

I. CAUSES OF SOIL SURFACE EROSION

A. General Considerations

A correct and complete analysis of the surface erosion process (indeed any physical process) must be based upon the fundamental laws of classical physics, i.e., the conservation of mass, momentum, and energy, and the second law of thermodynamics. The mathematical formulation of these principles and solution of the resulting governing equations in the context of surface erosion is not an easy task, as can be seen in the comprehensive works by Yalin (1972) and Raudkivi (1976). According to Raudkivi, it was R.A. Bagnold (well known for his fundamental studies of wind erosion) who proposed the title "Loose Boundary Hydraulics" as a general description of the physics of sediment movement.

Figure 1 indicates that the interaction of a fluid in motion with its erodible confining boundaries is the fundamental physical problem requiring

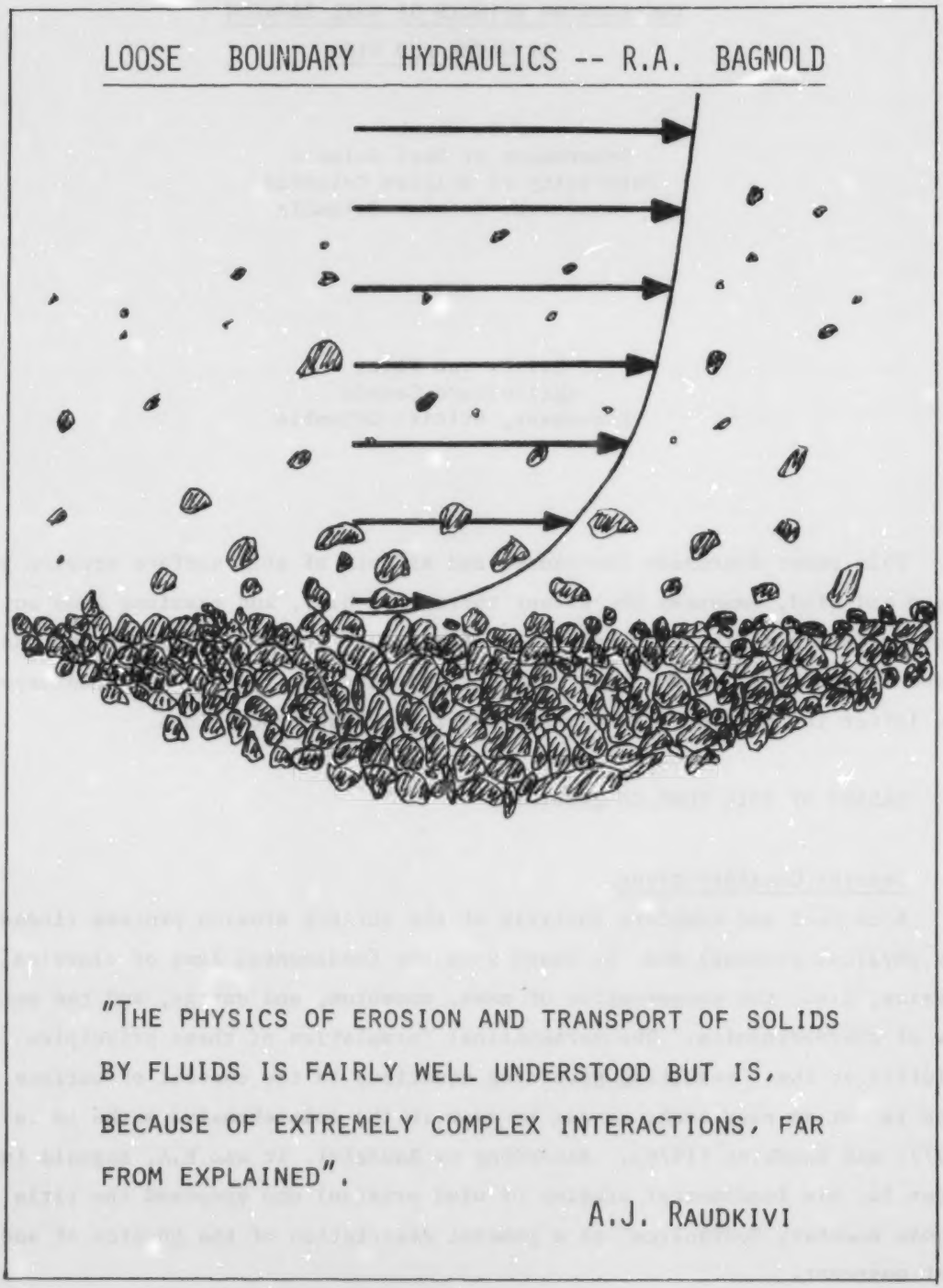

LOOSE BOUNDARY HYDRAULICS -- R.A. BAGNOLD
"THE PHYSICS OF EROSION AND TRANSPORT OF SOLIDS BY FLUIDS IS FAIRLY WELL UNDERSTOOD BUT IS, BECAUSE OF EXTREMELY COMPLEX INTERACTIONS, FAR FROM EXPLAINED".
A.J. RAUDKIVI

Figure 1.

analysis. According to Yalin, this is essentially a problem in "two-phase motion", i.e. solid and fluid phases. The major analytical difficulties have been found to be: (1) the turbulent motion of the fluid, and (2) the significant modification of the flow as the erodible material is entrained. The lack of a complete theory describing the phenomenon of turbulence is well known; it represents the last great unsolved problem in classical physics and affects our predictive capability in many other fields, e.g. meteorology-weather forecasting.

The composition of either the fluid or the erodible material does not alter the analysis of the two-phase motion represented by Figure 1. Thus at a fundamental level, the processes of surface erosion by wind or water are unified. Differences such as those due to the densities and viscosities of these fluids are important, but are accounted for explicitly in the theory. In addition, differences between "geologic" erosion and "accelerated" erosion (that caused by human activity) do not exist at the fundamental process level.

At this level, soil surface erosion may be envisioned as consisting of the three sequential stages illustrated in Figure 2. The detachment stage consists of a set of physical processes that results in the entrainment of either soil particles or aggregates by the transporting fluid. In the transport stage the entrained soil is moved along the soil surface by the fluid. Deposition of the entrained soil will take place when the flow is slowed for some reason. This may occur relatively close to the point of detachment, in which case significant erosion of a given site will then require many repetitions of the process both temporally and spatially.

If the major factors limiting the erosion process occur in either the detachment or transport stages then the erosion is termed "detachment-limited" or "transport-limited", respectively. Often this will vary with time and location on a given site. For example when rain falls on a dry soil, the erosion is usually transport-limited initially since most of the rainfall infiltrates into the soil. However should the rain continue for a long enough time, then following removal of the most easily erodible surface material the process becomes detachment-limited. The deposited material often has a high infiltrability and is easily detached so that further erosion of this material is often transport-limited.

B. Surface Water Erosion

A schematic diagram of the surface water erosion process, at a more detailed level, is presented in Figure 3. The factors of greatest importance

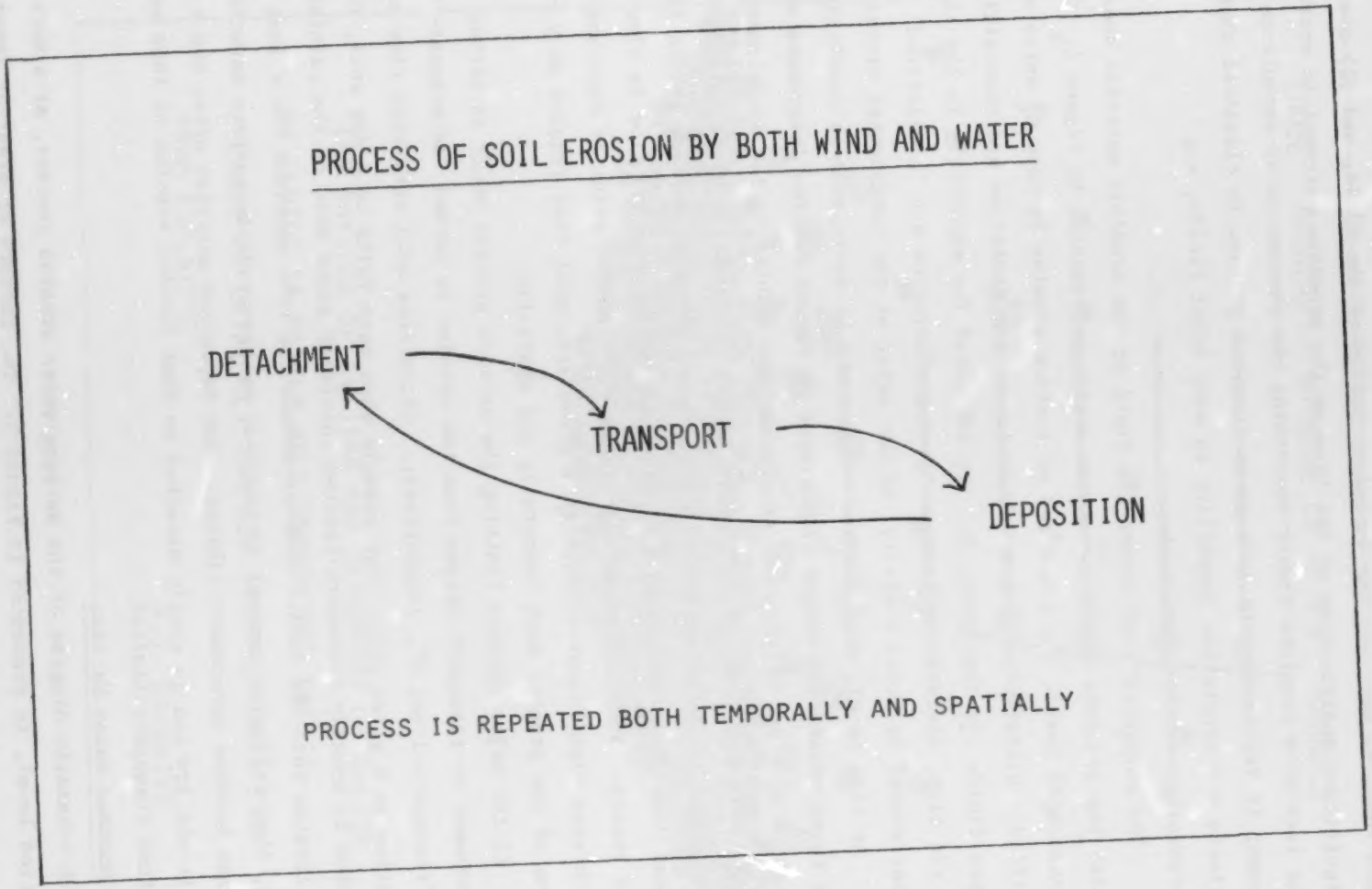

PROCESS OF SOIL EROSION BY BOTH WIND AND WATER
DETACHMENT
TRANSPORT
DEPOSITION
PROCESS IS REPEATED BOTH TEMPORALLY AND SPATIALLY

Figure 2.

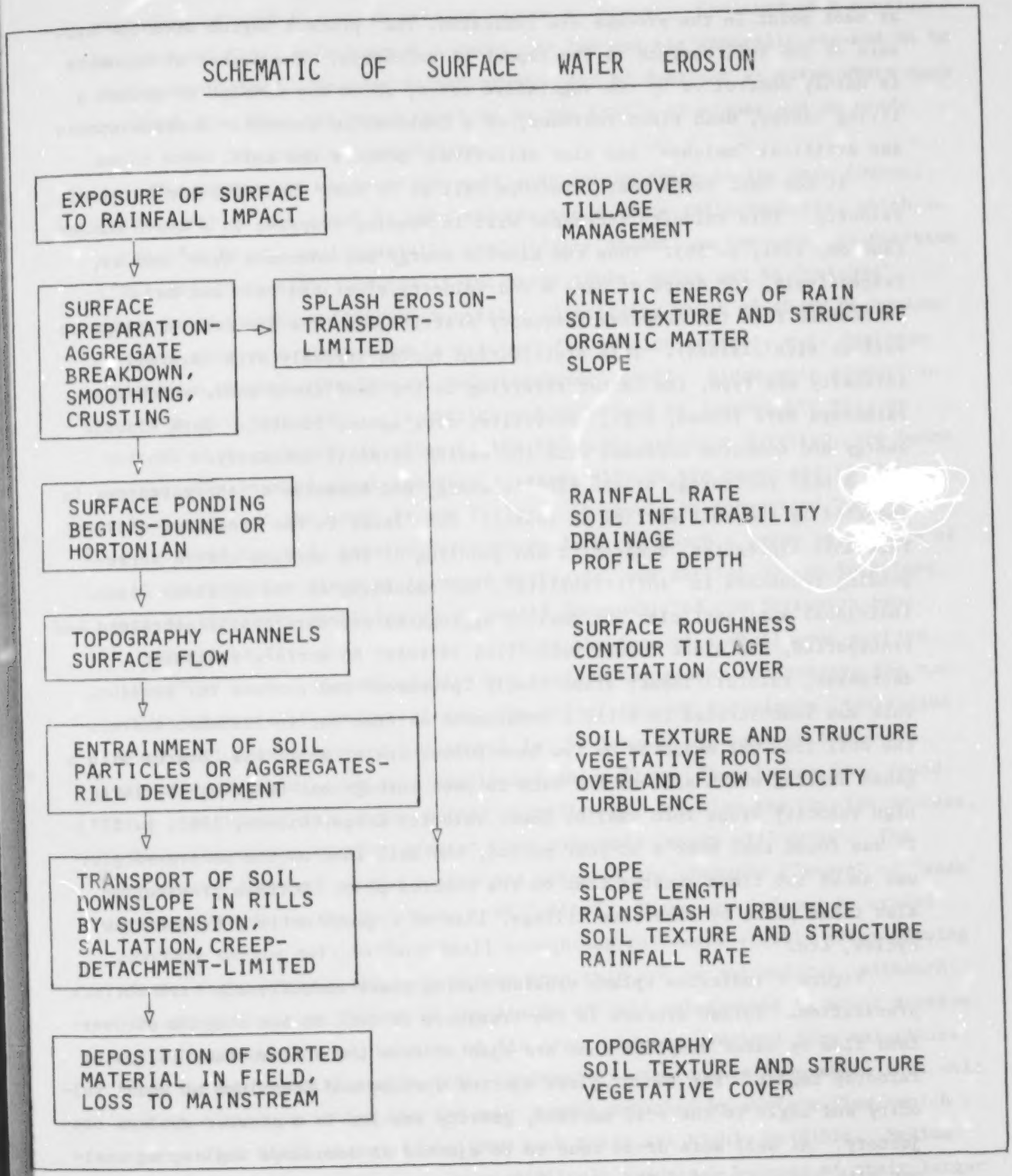

SCHEMATIC OF SURFACE WATER EROSION
EXPOSURE OF SURFACE TO RAINFALL IMPACT
CROP COVER
TILLAGE
MANAGEMENT
SURFACE PREPARATION-AGGREGATE BREAKDOWN, SMOOTHING, CRUSTING
SPLASH EROSION-TRANSPORT-LIMITED
KINETIC ENERGY OF RAIN
SOIL TEXTURE AND STRUCTURE
ORGANIC MATTER
SLOPE
SURFACE PONDING BEGINS-DUNNE OR HORTONIAN
RAINFALL RATE
SOIL INFILTRABILITY
DRAINAGE
PROFILE DEPTH
TOPOGRAPHY CHANNELS SURFACE FLOW
SURFACE ROUGHNESS
CONTOUR TILLAGE
VEGETATION COVER
ENTRAINMENT OF SOIL PARTICLES OR AGGREGATES-RILL DEVELOPMENT
SOIL TEXTURE AND STRUCTURE
VEGETATIVE ROOTS
OVERLAND FLOW VELOCITY
TURBULENCE
TRANSPORT OF SOIL DOWNSLOPE IN RILLS BY SUSPENSION, SALTATION, CREEP-DETACHMENT-LIMITED
SLOPE
SLOPE LENGTH
RAINSPLASH TURBULENCE
SOIL TEXTURE AND STRUCTURE
RAINFALL RATE
DEPOSITION OF SORTED MATERIAL IN FIELD, LOSS TO MAINSTREAM
TOPOGRAPHY
SOIL TEXTURE AND STRUCTURE
VEGETATIVE COVER

Figure 3.

at each point in the process are indicated. The process begins with the exposure of the soil surface to the impact of raindrops. The degree of exposure is mainly controlled by the vegetative cover, which may consist of either a living canopy, dead plant residues, or a combination thereof. Surface stones and artifical "mulches" can also effectively protect the soil.

It has been found that raindrops fall at or near the still air terminal velocity. This velocity increases with increasing dropsize in a known manner (Hudson, 1981, p. 56). Thus the kinetic energy and momentum ($\frac{1}{2}mv^2$ and mv, respectively, for drops of mass m and velocity v) of the rain can be determined from the dropsize frequency distribution (the fraction of drops in various size classes). This distribution varies strongly with rainfall intensity and type, the latter referring to the conditions under which the raindrops were formed, e.g., convective, orographic, frontal. Both kinetic energy and momentum increase with increasing rainfall intensity.

A high percentage of the kinetic energy and momentum of the raindrops is absorbed by the soil surface on impact. This leads to the breakdown of surface soil aggregates, compaction and puddling of the surface with a corresponding reduction in "infiltrability", and smoothing of the surface. Since individual soil particles and smaller aggregates are more easily entrained and transported, and since runoff velocities increase as surface roughness decreases, rainfall impact dramatically "prepares" the surface for erosion. This was demonstrated in a field experiment carried out in Zimbabwe wherein the soil loss was measured on two bare plots, one of which was covered with a gauze netting which allowed the rain to pass through but broke up the large high velocity drops into smaller lower velocity drops (Hudson, 1981, p. 277). It was found that over a 10-year period, the soil loss on the uncovered plot was about 100 times greater than on the covered plot. Surface preparation also takes place by excessive tillage, loss of organic matter, freeze-thaw cycles, etc.

Figure 3 indicates splash erosion taking place concurrently with surface preparation. Splash erosion is the transport of soil in the absence of overland flow by water droplets that are ejected from the soil surface following raindrop impact. For two droplets ejected upslope and downslope at equal velocity and angle to the soil surface, gravity results in a shorter upslope trajectory. As well more drops tend to be ejected at downslope angles, in analogy with the specular reflection of light beams by a mirror. Thus a net

transport of soil by splash erosion occurs on slopes. Compared with erosion by overland flow, splash erosion rates are low and are generally assumed to be transport-limited. However splash erosion can be dominant at sites where much overland flow does not occur, such as on the knolls of slopes and on sandy soils under low rainfall conditions.

The ponding of water on the soil surface can occur in two ways (Dunne, 1978): (1) if the rainfall rate exceeds the surface infiltrability, which is a function of the soil hydraulic conductivity as well as the rainfall duration ("Hortonian" runoff), and (2) if the water table, which may be "perched", rises to the surface ("Dunne" runoff). Identifying which of these mechanisms is occurring on a given site is critical for erosion control, e.g. drainage will be much more effective in reducing Dunne runoff. Since many productive soils in B.C. are relatively shallow and underlain by impermeable till or bedrock while rainfall is often of low intensity and long duration, the Dunne mechanism may be of great importance, especially on the coast and in the upland areas of the Lower Fraser Valley. It should be recognized that the majority of the U.S. erosion research to date, on which a large percentage of soil conservation planning is based worldwide, was carried out on locations east of the Rocky Mountains where runoff is usually of the Hortonian type.

Overland flow does not take place in the form of a continuous surface "sheet" of water; instead gravity and surface topography concentrate the runoff in channels of various sizes. The velocities and turbulence levels (and hence soil detachment and transport) in the largest of these channels are higher than would occur in a continuous sheet flow. Thus it has been found that the channelling of the runoff significantly enhances the erosion process, often determining whether greater than tolerable levels will occur. The erosion of the soil at the bottom and sides of the channels ("scour" or "wash" erosion) leads to the development of "rills". These are defined as eroded channels on the soil surface small enough not to remain visible after plowing of the soil. Eroded channels larger than this are termed gullies, although not all gullies are formed as the result of rill enlargement by scour erosion.

Vegetative cover, because of its drag, reduces overland flow velocities thus inhibiting rill development. Laboratory experiments have shown that silt and fine sand particles are the most easily detached by surface flow, which agrees with field observations that such soils are highly erodible. Medium and coarse sand particles are more difficult to detach because of their larger

size, i.e. in general the detaching forces of lift and drag on a particle vary as diameter-squared while immersed particle weight varies as diameter-cubed. Even in the absence of cohesion, clay-sized particles are more difficult to detach because their smoothness does not result in turbulent drag and lift. Transport in the rill flow of all these particles occurs by either suspension, saltation, or creep. In suspension, turbulent fluctuations lift the constantly settling particles back into the mainstream of the flow which then carries them farther downstream. In saltation the particles move in a series of low jumps along the soil surface, much like a rock skipping on the surface of a lake. Saltation does not require the flow to be turbulent, although turbulence does enhance this process. In creep the particles roll or slide over the soil surface. Similar remarks apply to the detachment and transport of aggregates by the rill flow. The sediment carried in saltation and creep is termed the "bedload". Clay, silt, and organic matter particles are mostly transported in suspension, while the sand fraction and aggregates move mainly as bedload.

The rate of rill development on a given site eventually declines for a number of reasons, e.g. the exposure of less erodible soil at depth, the protective effect of the nonerodible coarse fragments (stones, twigs, etc.) that accumulate in the rill, the formation of a deep narrow rill which leads to a reduction in flow velocities and turbulence levels. Erosion of well established rills is thus assumed to be detachment-limited. If and when rill enlargement ceases, i.e. when the rills reach a "dynamic-equilibrium" with the overland flow that led to their formation, soil erosion overall is determined by the rate of "interrill" erosion.

Splash erosion is included in interrill erosion as shown by the feedforward loop in Figure 3. Also included are processes of detachment and transport occurring in the shallower and/or finer surface channels generally not classified as rills. These channels are such that without the direct effect of raindrops splashing into the runoff contained by them, turbulence levels would be too low (i.e. the flow would be almost laminar) for significant soil detachment or transport to take place. It has been found that the rate of erosion in these channels increases with the depth of water to a depth of about one raindrop diameter, beyond which the influence of the splashing of the drops declines. Whether interrill erosion is significant compared with rill erosion is at present subject to debate (Thornes, 1980; Kirkby, 1980). As

mentioned previously for splash erosion, interrill erosion rates are low compared with rill erosion and are generally assumed to be transport-limited. However since the interrill eroded soil is carried into the high transport capacity rill flow, significant erosion can take place even after rill enlargement has ceased. A lower limit to the amount of soil lost from a field in a given season can be estimated by determining the product of the volume of the well-established rills and the surface bulk density.

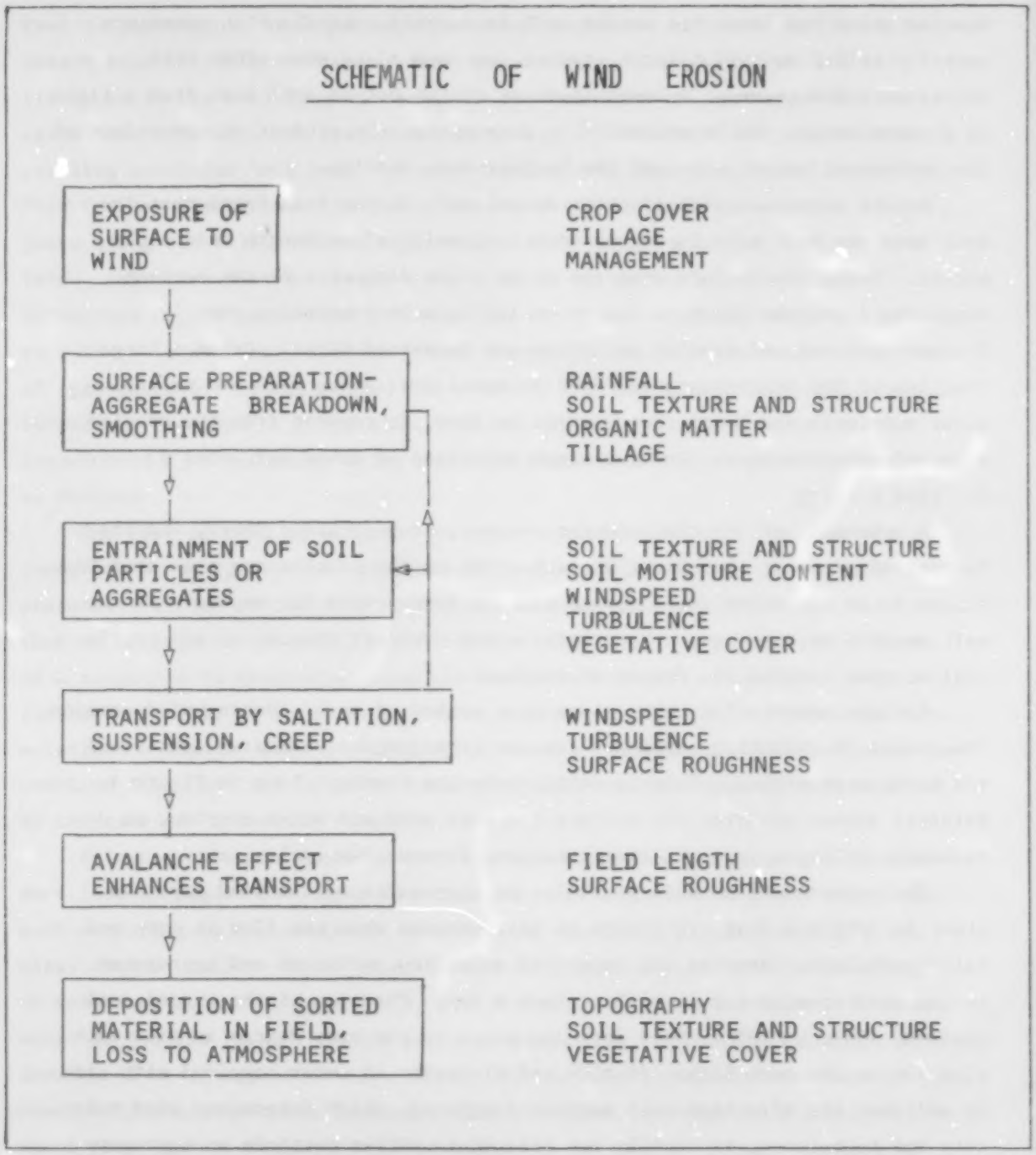
Runoff increases with distance downslope. It has been found that the soil loss per unit area increases with increasing slope length (and slope angle). Deposition occurs when the slope angle decreases or the surface roughness increases (perhaps due to an increase in vegetative cover). Coarser-textured and heavier particles are deposited first. Often a large fraction of the finer-textured, lighter particles, along with the valuable plant nutrients and pesticides carried by them, is removed from the erosion site and contributes to the downstream pollution of lakes and streams.

C. Wind Erosion

A schematic of the wind erosion process, at a detailed level, and the factors of greatest importance at each point in the process are presented in Figure 4. As for water erosion, the process begins with the exposure of the soil surface to the wind. Vegetative cover, surface stoniness, and artificial mulches control the degree of exposure.

Surface preparation takes place in a number of ways. During wind erosion the impact of saltating particles results in aggregate breakdown (abrasion) and surface smoothing. This is depicted by the feedback loop in Figure 4. Rainfall impact prepares the surface for both wind and water erosion, as do excessive tillage, loss of organic matter, freeze-thaw cycles, etc.

The entrainment of soil particles or aggregates by the wind may take place by lift and drag, as occurs in rill erosion when the flow is deep and fully turbulent. However the impact of saltating particles and aggregates during wind erosion may directly detach a large fraction of the eroded soil (Hudson, 1981, p. 268). This does not occur to the same degree in rill erosion due to the much higher density and viscosity of water compared with air. In addition the effective soil surface roughness, which determines wind velocity and turbulence, is usually not related to either particle or aggregate size (as in rill erosion) but to a larger scale of roughness such as that due


SCHEMATIC OF WIND EROSION
EXPOSURE OF SURFACE TO WIND
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MANAGEMENT
SURFACE PREPARATION-AGGREGATE BREAKDOWN, SMOOTHING
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SOIL TEXTURE AND STRUCTURE
ORGANIC MATTER
TILLAGE
ENTRAINMENT OF SOIL PARTICLES OR AGGREGATES
SOIL TEXTURE AND STRUCTURE
SOIL MOISTURE CONTENT
WINDSPEED
TURBULENCE
VEGETATIVE COVER
TRANSPORT BY SALTATION, SUSPENSION, CREEP
WINDSPEED
TURBULENCE
SURFACE ROUGHNESS
AVALANCHE EFFECT ENHANCES TRANSPORT
FIELD LENGTH
SURFACE ROUGHNESS
DEPOSITION OF SORTED MATERIAL IN FIELD, LOSS TO ATMOSPHERE
TOPOGRAPHY
SOIL TEXTURE AND STRUCTURE
VEGETATIVE COVER

Figure 4.

to ridging, surface vegetation, etc. This is because the depth of the flow in wind erosion is of the order of a few hundred meters, appropriate to the depth of the atmospheric boundary layer, whereas the depth of rill flow is of the order of a few centimeters.

In wind erosion the cohesive strength of the surface soil due to its water content affects the detachability of the soil particles or aggregates. The cohesive strength of a soil generally reaches a maximum somewhere between the "permanent wilting point" (1.5 MPa of tension) and the "liquid limit". It has been found that for detachment by wind to take place, the surface soil must be drier than the permanent wilting point. Since evaporative drying occurs from the soil surface downwards, the surface water content can fall below this threshold value even in areas of high precipitation. The greater runoff associated with water erosion reduces profile storage and may result in a lower surface water content. The behaviour of the cohesion-water content curve suggests that very wet soils may also be prone to wind erosion.

The transport of soil in wind erosion also occurs (in order of importance) by saltation, suspension, and creep. Saltation is dominant since it is a self-enhancing chain reaction, i.e., the impact with the soil surface of a saltating particle or aggregate results in the saltation in turn of at least one other particle or aggregate. In a similar manner suspension and creep are enhanced by saltation. For an initially sediment-free airflow, the rate of soil transport increases with distance downwind, until the transport capacity of the flow is reached. This "avalanche effect" results in an increase in soil loss per unit area with increasing field length in the direction of the prevailing wind. As in water erosion, deposition of the coarser-textured and heavier particles takes place first and is controlled by topography, surface roughness, vegetation, etc. The fine-textured and lighter particles may cause air pollution hundreds of kilometers downwind.

D. Models of Surface Erosion

Various mathematical models that predict the rate of suface erosion are possible (Figure 5). These range from "transparent" models, in which the processes are explicitly accounted for using the fundamental laws of classical physics, to "black box" models, in which an empirical relationship between erosion rate and various climate, soil, topographic, and management variables is developed from field measurements of soil loss. The advantage of the

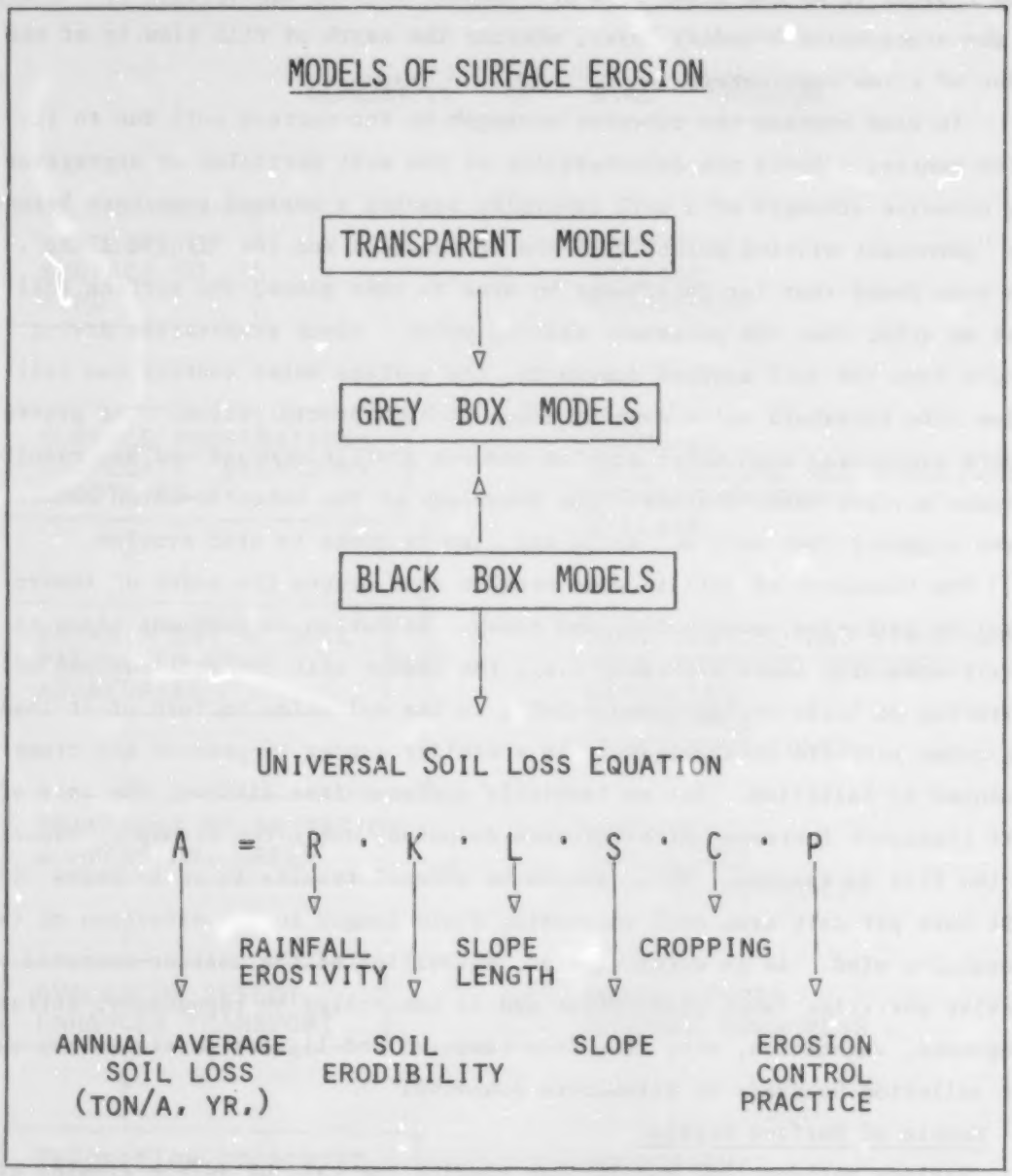
MODELS OF SURFACE EROSION
TRANSPARENT MODELS
GREY BOX MODELS
BLACK BOX MODELS
UNIVERSAL SOIL LOSS EQUATION
A = R · K · L · S · C · P
RAINFALL EROSIVITY
SLOPE LENGTH
CROPPING
ANNUAL AVERAGE SOIL LOSS (TON/A, YR.)
SOIL ERODIBILITY
SLOPE
EROSION CONTROL PRACTICE

Figure 5.

latter is their simplicity, while the former have greater flexibility. Presently much research is concentrated on "grey box" or semi-empirical models.

Probably the best known black box model of surface water erosion is the "Universal Soil Loss Equation" (USLE)(Wischmeier and Smith, 1978). In this model the annual average soil loss is expressed as a product of rainfall, soil, slope length, slope, cropping, and erosion control practice factors. These factors can be estimated using nomograms and tables developed at locations scattered throughout the U.S., or determined from local soil-loss measurements on standard field plots.

II. EFFECTS OF SOIL SURFACE EROSION

The field, downstream, and downwind effects of soil surface erosion are listed in Table 1. The most obvious field effect is the soil loss, which can be as great as 15 cm in 20-50 years for surface water erosion and 15 cm in 1-5 years for wind erosion (Troeh, Hobbs, and Donahue, 1980, p. 87 and p. 117). Tolerable soil loss rates are usually assumed to be in the range of 5-10 mt ha^{-1} yr^{-1} or 15 cm in 200-400 years. The topsoil layer in the soil profile usually has the highest "physical fertility" (i.e. soil structure factors that determine plant growth, such as soil infiltrability, aeration, mechanical resistance to rooting, etc.) and chemical fertility (i.e. available plant nutrients). Thus the loss and degradation of this layer by the surface erosion process is particularly detrimental. Hydrologic changes result from the reduction in root-zone depth due to the soil loss and the decrease in infiltrability, both of which increase the probability of plant moisture stress. The exposure of denser layers at depth and/or the degradation of surface structure makes tillage more difficult and costly. If gullies develop, the narrower field that results also has this effect. Textural sorting and burial and abrasion of seedlings occur during the deposition of soil.

A major downstream and downwind effect is the siltation of ponds, reservoirs, canals, etc. This increases the maintenance costs and decreases the lifetime and capacity of these structures. The greater runoff and reduced drainage associated with water erosion in the field result in higher peak flows and lower base flows on the watershed scale. The former causes greater downstream flooding and erosion, while the latter can determine downstream water availability and quality during periods of high demand. Water erosion

EFFECTS OF SOIL SURFACE EROSION

A. FIELD EFFECTS

1. SOIL LOSS
2. PHYSICAL FERTILITY LOSS
3. CHEMICAL FERTILITY LOSS
4. HYDROLOGIC CHANGE
5. MORE DIFFICULT AND COSTLY TILLAGE
6. REDEPOSITION EFFECTS ON FIELD, CROP
7. REDUCTION IN CROP YIELD AND QUALITY, LAND VALUES

B. DOWNSTREAM AND DOWNWIND EFFECTS

1. SILTATION OF PONDS, RESERVOIRS, CANALS, ETC.
2. HYDROLOGIC CHANGE - WATERSHED SCALE
3. POLLUTION BY NUTRIENTS AND SILT
4. DAMAGE TO ENGINEERING AND FARM STRUCTURES

TABLE 1.

can result in the eutrophication, acidification, salination, and poisoning of streams, ponds, and lakes. Wind erosion can cause both long- and short-term human health problems and may have a climatic impact. Abrasive damage to engineering and farm structures and machinery can result from either water or wind erosion.

All of the above field effects reduce crop yields and quality, although it may be possible to maintain these with greater inputs such as fertilizer, irrigation, etc. Not all of the above field, downstream, and downwind effects are of equal importance in a given region. Assessment of their cost to specific groups, such as farmers or to society in general, especially in the long-term is often difficult.

III. ASSESSMENT OF SURFACE EROSION IN B.C.

Soil erosion due to forestry in B.C. is discussed in two of the other papers in these proceedings. It seems that this type of erosion is restricted to road-related problems and clear-cut areas, most often in west coast logging. Wind erosion, although sometimes a local problem, is not widespread in B.C. Consequently, this assessment of the surface erosion problem in B.C. only considers water erosion on agricultural land.

Of the total land area of this province (89.387 million ha), only 4% is considered suitable for crop production (Agricultural Capability Classes 1-4) and almost 2.5% represents the 1981 total area in farms. Of this total agricultural area (2.18 million ha), 43% is in active cultivation (B.C. Min. Agr. Food, 1982). It is this actively managed farmland (improved farmland) that is of most importance for this erosion assessment. Cultivated land includes all actively managed land, such as cropland, improved pasture, and grazing land. Unimproved land, such as woodland, rangeland, residential, recreation, and utility lands are not included in the assessment.

The assessment is based on: (1) the intensity of agricultural use (cultivated area as percent of total farmland) and (2) the proportion of total cultivated land in B.C.

A. Intensity of Agricultural Use

The cultivated area is now considered as a percentage of the area in farms (agricultural areas) for 29 census districts, which are subdivisions of Agricultural Reporting Regions (B.C. Min. Agr. Food, 1982). Each district

was classified in one of four percentage classes, as shown in Figure 6. Most of the Mainland Region stands out as having 80% of the agricultural area in cultivation. The Peace Region, most of the Okanagan and Kootenay Regions, and part of the Island Region have between 50-75% under cultivation. The rest of the province has less than 50% of agricultural land under active cultivation.

B. Proportion of Total Cultivated Land

Distribution of the 1981 cultivated area, expressed as a percentage of the total provincial cultivated area, is presented in Figure 7 for B.C. Agricultural Reporting Regions. Also, the general location of the agricultual land in B.C. is indicated in black. Forty percent of the 1981 total provincial area in cultivation is located in the Peace Region. The Island and Kootenay Regions have 3 and 4%, respectively, with the rest of the regions between 9 and 13% of cultivated land.

C. Erosion Risk Ranking

The above two factors, combined with present knowledge on erosion in these areas, were considered in the erosion risk ranking for each Agricultural Reporting Region (Figure 8). The Peace Region is the highest erosion risk (1) area in B.C., followed by a medium high erosion risk (2) area in the Mainland Region. Despite the higher intensity of agricultural use in the Mainland Region (80% of total farmland is in cultivation), it only has 9% of the total cultivated area in B.C. compared to 40% for the Peace Region. Also, the seriousness of the erosion problem in the Peace Region has been repeatedly documented, not only regarding interrill and rill erosion, but also for gully erosion problems (Albright, 1939; Rowles, 1948; Laird, 1950; Chapman et al., 1952; Johnson, 1961; Farstad et al., 1965). More recently, there is good evidence and more knowledge and experience in support of this earlier documentation (Van Vliet, 1979; Klein, 1980; Shephard, 1980; Van Vliet, 1983).

The Okanagan, Island, Kootenay, and Omineca Regions were ranked as moderate erosion risk (3) areas. They all have between 40 and 55% of total farmland in cultivation. Areas with low erosion risk (4) are the Cariboo and Thompson Regions, with 30-25% of total farmland in cultivation, respectively. If more knowledge and information on erosion for these different regions becomes available, or if the intensity of agriculture changes significantly, the relative ranking of erosion risk for these regions may change in the future.

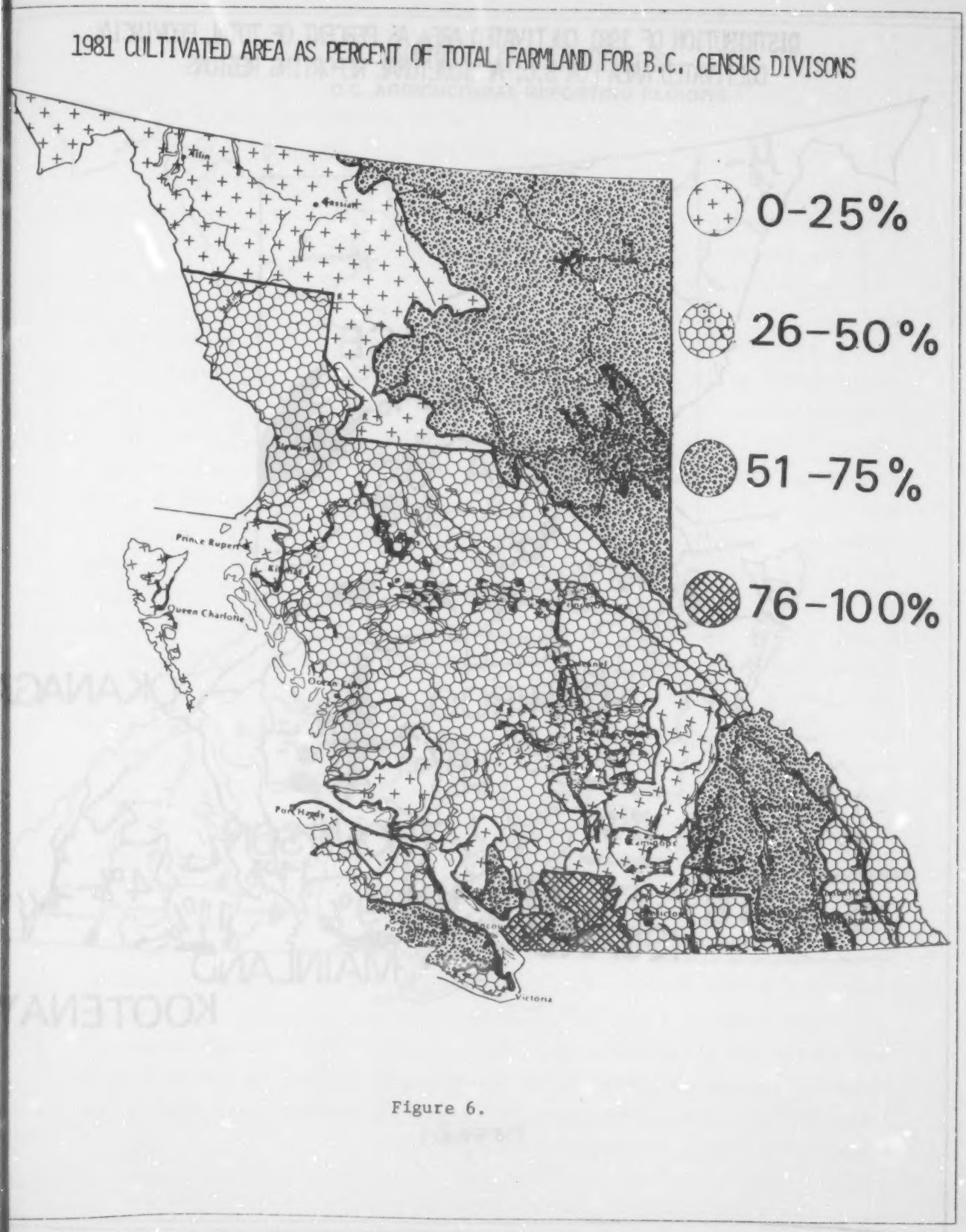
1981 CULTIVATED AREA AS PERCENT OF TOTAL FARMLAND FOR B.C. CENSUS DIVISONS
0-25%
26-50%
51 -75%
76-100%
Prince Rupert
Queen Charlotte
Port Hardy
Victoria

Figure 6.

DISTRIBUTION OF 1981 CULTIVATED AREA AS PERCENT OF TOTAL PROVINCIAL CULTIVATED AREA FOR B.C. AGRICULTURAL REPORTING REGIONS

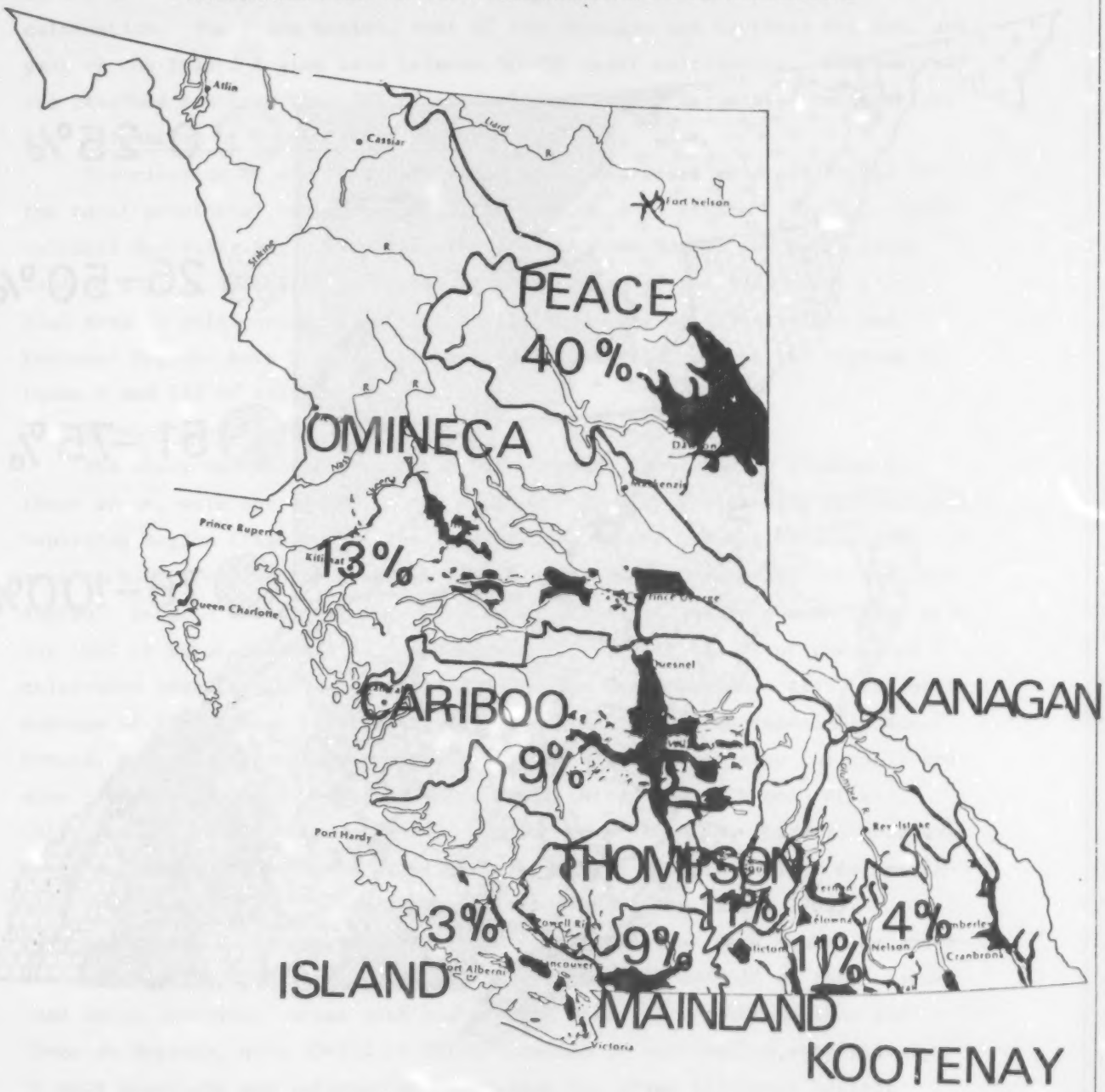

Figure 7.

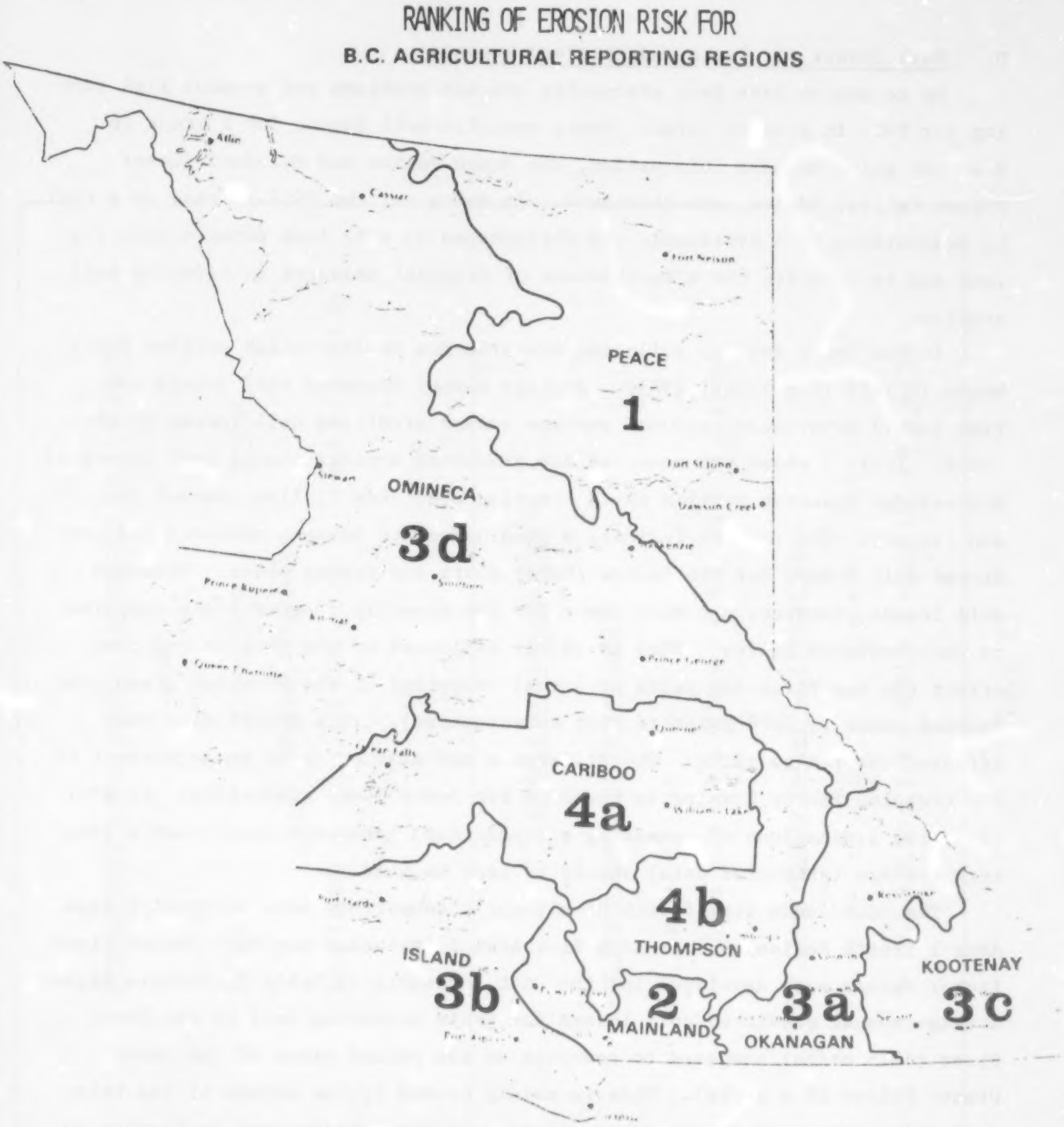
RANKING OF EROSION RISK FOR
B.C. AGRICULTURAL REPORTING REGIONS
PEACE
1
OMINECA
3d
CARIBOO
4a
4b
THOMPSON
ISLAND
3b
2
MAINLAND
3a
OKANAGAN
KOOTENAY
3c

Figure 8.

D. Soil Losses for Peace and Mainland Regions

Up to now we have been discussing erosion problems and erosion risk ranking for B.C. in general terms. Next, specific soil losses for 2 areas in B.C. for which we have information, the Peace Region and Mainland (Lower Fraser Valley) Region, are discussed. In doing so, the USLE is used as a tool to demonstrate in a systematic way differences in soil loss between both regions and to evaluate the effectiveness of remedial measures in reducing soil erosion.

In the Peace Region, soil-loss measurements on controlled erosion plots began in 1979 (Van Vliet, 1983). Average annual measured soil losses over time should eventually approach average annual predicted soil losses by the USLE. Table 2 shows the measured and predicted average annual soil losses at Beaverlodge Research Station for 3 cropping practices (fallow, annual crop, and fescue). The results indicate a good agreement between measured and predicted soil losses for the fallow (bare) plots and fescue plots. Measured soil losses, however, are much lower for the annually cropped plots compared to the predicted losses. This is partly explained by the erosion reducing effect (in the first few years of annual cropping) of the previous grass crop (plowed under in 1979 prior to plot construction). This should also have affected the fallow plots. The difference may also point to an adjustment of the cropping factor C-value in the USLE for Peace River conditions. In addition, the limitations of comparing a 3-year mean (measured data) with a long-term average (predicted data) should be kept in mind.

The USLE lends itself very nicely for a comparison between Erosion Risk Area 1 (Peace Region) and Erosion Risk Area 2 (Mainland Region). Generalized factor values were developed for the USLE. Results in Table 2 indicate higher average annual predicted soil losses for grain producing land in the Peace River (11.5 mt/ha) compared to rowcrops on the upland areas of the Lower Fraser Valley (8.4 mt/ha). This is mainly caused by the nature of the rainfall (high intensity storms expressed by a higher R-value) and by farming on much longer slopes (expressed by a higher LS-value) for the Peace Region. These differences are partly offset by the higher C-value for rowcrops in the Fraser Valley Region. There is about 3 mt/ha per year more soil loss in the Peace Region than in the Mainland Region.

AVERAGE ANNUAL SOIL LOSSES, BEAVERLODGE EROSION PLOTS

(mt/ha)

	Fallow	Annual Crop (Barley, Rapeseed)	Fescue
Measured (3-year mean)	16.5 (3-40)	1.1 (0.5 - 1.5)	1.9 (0.5 - 3.0)
Predicted	17.4	4.4	1.4

AVERAGE ANNUAL SOIL LOSS

For Peace River Cultivated Land:

$A = R \cdot K \cdot LS \cdot C \cdot P =$

$= 27.5 \times 0.31 \times 2 \times 0.30 \times 1 = 5.1$ t/a = 11.5 mt/ha

For Lower Fraser Valley Cultivated Land:

$A = R \cdot K \cdot LS \cdot C \cdot P =$

$= 15.5 \times 0.30 \times 1.6 \times 0.50 \times 1 = 3.7$ t/a = 8.4 mt/ha

TABLE 2.

EROSION CONTROL PRACTICE FACTOR

Practice	P
cross-slope farming, without strip cropping	0.75
contour farming, without strip cropping	0.50
cross-slope farming, with strip cropping	0.37
contour farming, with strip cropping	0.25

CROPPING FACTOR

Crop	C
Fallow	1.00
Row Crops	0.50
Cereal Grain (Conventional Tillage)	0.30
Cereal Grain (Zero Tillage)	0.12
Forage	0.08
Permanent Pasture	0.03
Trees	0.02

CONSERVATION PRACTICE CALCULATION

$$A = R \cdot K \cdot L \cdot S \cdot C \cdot P = 27.5 \times 0.31 \times 2 \times 0.30 \times 1 = 5.1 \text{ t/a } (11.5 \text{ mt/ha})$$

$$CP = \frac{A}{RKLS} = \frac{3}{27.5 \times 0.31 \times 2} = 0.18$$

OPTIONS

Strip Cropping, Cross Slope: $CP = 0.30 \times 0.40 = 0.12$

Conservation Tillage: $CP = 0.18 \times 1 = 0.18$

TABLE 3.

IV. SOIL CONSERVATION PRACTICES

There are two groups of soil conservation measures, most of which are readily available to farmers. The first group is associated with the erosion control practice factor P, and the second with the cropping factor C in the USLE (Table 3). The C-values shown were developed for Southern Ontario (Van Vliet and Moore, 1977). The USLE is used in this table to demonstrate how soil conservation practices can reduce soil erosion. Say we want to reduce soil losses in the Peace Region for cereal grain crops tilled up and down the slope (C = 0.30) to 6.8 from 11.5 mt/ha. The USLE is solved for the product of C and P, which are the only 2 factors that can be readily influenced by farm management practices. We now select a practice that does not exceed 0.18 for the combined CP factor. The options for the farmer are: (1) strip cropping across the slope which yields a CP of 0.12, and (2) some form of conservation (minimum) tillage, such as disc and plant in one operation or zero tillage, which yields a CP of 0.18.

V. CONCLUSIONS

1. At a fundamental level, the processes of soil surface erosion by wind and water are unified. At this level, the erosion process consists of three sequential stages: detachment, transport, deposition.
2. Due to the low intensity, long duration rainfall on the B.C. coast and in the Lower Fraser Valley, the surface water erosion process on shallow soils underlain by impermeable layers on this region will differ from that which occurs east of the Rocky Mountains.
3. The effects of surface erosion are felt both at the erosion site as well as downstream and downwind.
4. Agricultural soil losses due to interill and rill erosion are serious problems in both the Peace and Lower Fraser Valley Regions. In these areas present levels of soil loss are too high for sustained crop production.
5. Widespread use of soil conservation measures (readily available but not currently used) will result in significant reductions in agricultural soil loss.
6. More money should be made available for regional soil erosion research and demonstration projects to compare and evaluate the effectiveness of soil conservation practices in reducing soil erosion.

VI. REFERENCES

Albright, W.D., 1939, The Menace of Water Erosion in the Peace, Scientific Agriculture, Vol. XIX, No. 5, pp. 241-248.

B.C. Ministry of Agriculture and Food, 1982, British Columbia 1981 Agricultural Statistics Yearbook, B.C. Min. Agr. Food, Victoria, B.C.

Chapman, J.D., J.S. Gilmore, D. Sutherland, 1952, Peace River - South Land Utilization Survey, 1948-1951, Division of Land Utilization Research and Survey, Lands Service, Department of Lands and Forests, Victoria, B.C.

Dunne, T., 1978, Field Studies of Hillslope Flow Processes, In: Hillslope Hydrology, M.J. Kirkby (ed.), J. Wiley & Sons, Toronto, pp. 227-293.

Farstad, L., T.M. Lord, A.J. Green, H.J. Hortie, 1965, Soil Survey of the Peace River Area in British Columbia, Report No. 8 of the B.C. Soil Survey, Vancouver, B.C., pp. 104-105.

Hudson, N., 1981, Soil Conservation, 2nd ed., Cornell University Press, Ithaca, New York.

Johnson, W.E., 1961, Wind and Water Erosion in Western Canada, Agric. Inst. Review, pp. 12-15.

Kirkby, M.J., 1980, Modelling Water Erosion Processes, In: Soil Erosion, M.J. Kirkby and R.P.C. Morgan (eds.), J. Wiley and Sons, Toronto, pp. 183-216.

Klein, M., 1980, A Gully Erosion Study in a Selected Agricultural Area of the B.C. Peace River Region, B.Sc. Thesis, Bio-Resource Eng., Univ. of B.C.

Laird, D.G., 1950, Problems Related to the Soils of British Columbia, In: Transactions of the third B.C. Nat. Res. Conf., Feb. 15, 16, 1950, Victoria, B.C., pp. 11-31.

Raudkivi, A.J., 1976, Loose Boundary Hydraulics, Pergamon Press, Toronto.

Rowles, C.A., 1948, Soil Erosion in the Peace River Block of British Columbia, In: Proceedings of the B.C. Agronomists Association, Jan. 19-21, 1948, pp. 59-66.

Shephard, B., 1980, Erosion of Land In the Peace River Region, Inf. Bull. No.3, Alberta Environment Conservation Authority.

Thornes, J.B., 1980, Erosional Processes of Running Water and their Spatial and Temporal Controls: A Theoretical Viewpoint, In: Soil Erosion, M.J. Kirkby and R.P.C. Morgan (eds.), J. Wiley and Sons, Toronto, pp. 129-182.

Troeh, F.R., J.A. Hobbs, and R.L. Donahue, 1980, Soil and Water Conservation for Productivity and Environmental Protection, Prentice-Hall Inc.

Van Vliet, L.J.P., 1979, Soil Erosion in British Columbia's Peace River Region, Extension Brochure, B.C. Ministry of Agriculture, Victoria, B.C.

Van Vliet, L.J.P., 1983, Soil Erosion Measurements from Plots in the Peace River Region, Progress report 1979-1982, Agriculture Canada, B.C. Pedology Unit, Vancouver, B.C.

Van Vliet, L.J.P. and M. Moore, 1977, Case Studies - Water Erosion Problems and Solutions, In: Soil Erosion, In-Service Training Seminar for Ontario Ministry of Agriculture and Food, Oct., 1977, Toronto, Ontario.

Wischmeier, W.H. and D.D. Smith, 1978, Predicting Rainfall Erosion Losses, A Guide to Conservation Planning, U.S. Department of Agriculture, Agriculture Handbook No. 537.

Yalin, M.S., 1972, Mechanics of Sediment Transport, Pergamon Press, Toronto.

DEGRADATION EFFECTS OF ACIDIFICATION

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ABSTRACT

Fertilizers are the major cause of soil acidification in agricultural areas of B.C. This has been demonstrated by experiments which have shown depression of soil pH by fertilizer applied to grain crops in the Peace River area and to tree fruit crops in the Okanagan. Acid precipitation, arising from anthropogenic emissions of sulpher and nitrogen oxides, is deposited mainly along the southern coast. However, soil has been acidified by a local source of sulphur dioxide in the Southern Interior. Acidification of soils causes release of Al and Mn which are toxic to many agricultural crops and perhaps forest trees. Soil acidity also decreases the availability of N and P and lessens Rhizobia bacteria activity. All the major agricultural areas in B.C. have significant proportions of acid soils with the greatest concentration in the coastal areas but with the most extensive amount in the Peace River area. Basic N fertilizers are an alternative to acidifying N fertilizers. Emissions of sulphur dioxide can be greatly reduced by scrubbers in smoke stacks and emissions of nitrogen oxides can be reduced by exhaust controls on motor vehicles.

INTRODUCTION

Media attention to acid precipitation, popularly termed "acid rain", has made it a household word in Canada. The most dramatic and devastating of the destructive effects of acid precipitation is on the aquatic systems, with the resulting dead lakes. The impact of acid precipitation on terrestrial systems, including soils, is more difficult to measure. Probably the most difficult to measure of all is acidification of forest soils and its consequent effect on

wood production. For agricultural soils in B.C., as in many other areas, acidification by precipitation is far exceeded by acidification from fertilizers. This paper will explore the sources of acidification for both agricultural and forest soils and the consequent effect on production and of means that can be taken to lessen this form of soil degradation.

CAUSES OF ACIDIFICATION

Soil Sensitivity to Acidification

In general, soil sensitivity to acidification is inversely related to the buffering capacity (BFC) of the soil, but the role of this property is conditioned by the pH of the soil (Holowaychuk and Lindsay 1982). Alkaline soils are highly buffered and are not sensitive to acidification. Soils with pH 5.5-7.0 have much less buffering capacity than those with pH 5.0 and below. Apparently the stronger buffering capacity below 5.0 is due to the controlling influence of Al on the degree of acidification in that pH range.

The BFC was defined by Bache (1980) as the amount of acid or base required to change the pH in the soil by one unit, and it was indicated that cation exchange capacity is the most important factor that determines BFC. However, exchangeable bases only were considered by Wang and Coote (1981) to reflect the soils capacity to neutralize acid precipitation in eastern Canada, and they defined three soil sensitivity classes on that basis. In B.C., a soil sensitivity map at 1:1,000,000 scale is being developed; soil depth to bedrock, type of bedrock, upper and lower solum acidity and texture are being used to form the sensitivity classes (J.H. Wiens, B.C. Ministry of Environment, Victoria, B.C., personal communication).

Acidification by Natural Causes

Several natural sources cause acidification of soils. Bache (1980) estimated that CO_2 in soil water annually contributes an equivalent amount of acidity as does 17 kg S/ha converted to H_2SO_4. It was also suggested that acidification from organic acids on decomposition of plant residue can be considerable, though it is highly variable, depending on the kind and amount of residue.

Oxidation of pyrite (FeS), present in marine shales, has caused the

formation of acid soils, notably the Boundary series, in the Peace River area.

Acidification by Fertilizers

Fertilizers are the major source of soil acidification on agricultural land in B.C. The acidity from fertilizers is produced upon nitrificiation of NH_4 in NH_4-containing and NH_4- producing fertilizers, and on leaching of NO_3^-, $SO_4^=$ and Cl^- ions from fertilizer (Gasser 1973). The acidity released by nitrificiation may be represented as follows:

$$NH_4^+ + 2O_2 \xrightarrow{\text{nitrification}} NO_3^- + H_2O + 2H^+$$

A method for determining the acidity and basicity of fertilizers was developed by Pierre (1933). In theory, it would require 3.6 kg of $CaCO_3$ to neutralize the acidity produced from 1 Kg N. The $SO_4^=$ ion in ammonium sulphate requires compensating ions and thus the theoretical requirement for that fertilizer is increased to 7.2 kg of $CaCO_3$ per 1 kg of N. The actual acifification by NH_4 is usually less than theoretical because of NH_4 volatilization and crop use of the NH_4 ion.

Several experiments on acidification by fertilizers have been conducted on B.C. soils. In the Peace River area, fertilizers applied to Donnelly soil, a medium textured Gray Luvisol, caused a rapid drop in soil pH (Hoyt and Hennig 1982). Four consecutive applications to barley of N at 139 Kg/ha caused the pH to decrease by 0.43 units (Fig. 1). The fertilizer also caused the pH to fall, though to a lesser extent, in Josephine soil, a fine textured Gleysol.

In many Okanagan orchards, the soil beneath the trees is acid while it is neutral in the work rows, an extreme sample of which is shown in Table 1. These soils when in the virgin state had a neutral or alkaline reaction. The fertilizers have been applied mainly beneath the trees and that, possible together with bare ground from herbicides, has caused the acidification. The acidity usually extends to a 30-cm depth or slightly below but acidity has been measured in some cases to 90-cm depth (Hoyt, unpublished data).

Acidification by Acid Precipitation

Acid precipitation consists of wet deposits of rain and snow and dry deposits of SO_2 to soils and crops. Normal rain, has a pH of 5.6 and pH below this is usually caused by anthropogenic emissions of sulphur dioxide and

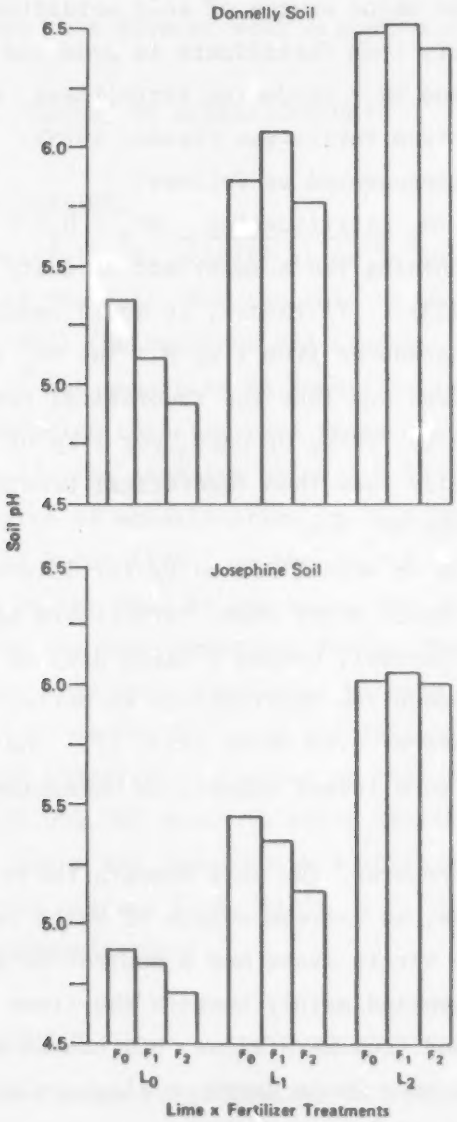
Donnelly Soil
Josephine Soil
Soil pH
6.5
6.0
5.5
5.0
4.5
F0 F1 F2
L0
L1
L2
Lime x Fertilizer Treatments

Figure 1

nitrogen oxides. Sulphur dioxide comes from smelting of non-ferrous metals, fossil-fueled power plants and sour gas processing plants. Half of the nitrogen oxides comes from motor vehicle exhausts and most of the remainder from industrial activities. In B.C., it is estimated that annual anthropogenic emissions amount to 368 tonnes of sulphur dioxide and 195 tonnes of nitrogen oxides (Environment Canada 1981).

Table 1. Soil pH in a Kelowna orchard

		Soil pH	
Site no.	Soil depth, cm	Under the trees	In the work rows
1	0-15	3.9	6.9
	15-30	4.0	6.3
2	0-15	4.2	6.0
	15-30	4.2	6.1
3	0-15	4.6	7.4
	15-30	7.2	7.6

In order to monitor precipitation chemistry, Environment Canada operates eight CANSAP (Canadian Network for Sampling Precipitation) Stations in B.C. The average precipitation pH, from 1977 to June 1981, ranged from 4.89 at Vancouver to 5.91 at Prince George (Table 2). However, it was suspected that the CANSAP coastal stations were all near local sources of pollution. In order to augment the Vancouver Station, a network of 14 stations were recently placed in metropolitan Vancouver, the adjacent mountains and rural parts of the Fraser Valley (Nikleva 1982). Precipitation collected during January-March 1982 showed slightly higher pH readings at the mountain stations with substantially higher readings from the valley stations. The group averages for the City and Valley stations were pH 4.77 and 5.40 respectively. These results, though very preliminary, pose questions for maps showing precipitation pH less than 5.0 stretching inland along the southern coast of B.C.

Acid precipitation in B.C. can acidify soils as was shown in the classic work of Katz et al. (1939). They reported that SO_2 emitted from a large smelter at Trail, B.C. lowered the soil pH to approximately 3.5 for a distance of at least 20 km, as compared to a natural soil pH of 5 to 6 at greater distances. Nyborg and Walker (1977) suggested that the direct absorption by soil of SO_2, which is transformed to H_2SO_4 in the soil, was much more important

than were wet deposits of acid precipitation downwind from natural gas plants in Alberta. Perhaps a similar situation exists for natural gas plants in northern B.C.

*Table 2. Precipitation pH values at CANSAP Stations in B.C. (Volume weighted averages for 1977-June, 1981)

Station	No.of measurements	Average pH
Vancouver	37	4.89
Terrace	39	5.21
Revelstoke	21	5.43
Prince George	43	5.91
Port Hardy	46	5.09
Kelowna	41	5.40
Fort St. John	33	5.41
Fort Nelson	36	5.61

*S. Nikleva, Scientific Services Division, Environment Canada, Vancouver, B.C., personal communication.

EFFECTS OF ACIDIFICATION

Agriculture

Several conditions are caused by soil acidity that are harmful to crop growth. Toxic Al comes into solution below pH 5.5 Most of the major crops of the Peace River area, barley, wheat, rapeseed and alfalfa are sensitive to Al toxicity (Hoyt et al.1974). Toxic Al could also be harmful to corn in the Lower Mainland. Although Mn is an essential nutrient for plants, it can also occur in toxic quantities below pH 5.5. Manganese is toxic to rapeseed. It is also toxic to 'Red Delicious' apples in the Okanagan by causing internal bark necrosis (bark measles) and slow growth of young trees (Fisher et al. 1977).

Losses of exchangeable bases upon soil acidification have implications to crop production. Both Ca and Mg were leached much more rapidly than was K in Okanagan orchard soils (Hoyt and Neilsen, unpublished data). This could create cation imbalances such as high K:Mg ratios and accentuate Mg deficiencies in fruit trees.

Soil acidity restricts Rhizobia bacteria activity. For alfalfa, this restriction occurs at pH <6.0, and could therefore be harmful to alfalfa

production in most of the farming areas of B.C. Nitrification decreases with decreasing soil pH. Phosphorus availability can also be decreased by soil acidity due to formation of low soluble Al and Fe phosphates.

Damage caused by soil acidity is reflected in yield response to lime. The response to lime seems to be the same whether the soil is naturally acid, acidified by fertilizers or acidified by anthropogenic emissions. An example of yield response is that of barley grown on five soils in the Peace River area from lime applied in 1970 (Hoyt and Hennig, unpublished data). The yield increases during 1971-81 amounted to an average of 0.8 tonnes/ha annually (Table 3). Alternatively this much yield loss would occur as a result of soil acidity.

Table 3. Increases in yields of Galt barley in the Peace River area from lime applied in 1970

	Tonnes/ha increase from liming				
	Soil and its original pH				
Year	Alcan pH 5.8	Donnelly pH 5.5	Buick pH 5.6	Josephine pH 4.9	Landry pH 5.4
1971	-0.07	0.79	-0.07	0.20	0.55
1972	0.35	0.73	0.81	2.18	1.28
1973	-	0.73	1.02	1.32	-
1974	1.21	0.83	1.39	1.02	1.54
1975	-0.03	0.39	-	1.55	0.27
1976	-	-	-	1.34	-
1977	0.05	0.59	0.51	2.37	0.99
1978	0.18	0.74	1.08	1.19	0.44
1979	-	-	-	-	-
1980	1.14	1.26	1.44	1.04	0.80
1981	0.27	0.38	1.19	0.47	0.17
Average (1971-81)	0.39	0.72	0.92	1.27	0.76

Agriculture

Acid soils occur in all the major agricultural areas of B.C. (Figure 2). Some of the soils were acid in their virgin state. The Alcan series, an extensively farmed soil in the Peace River area was acid. Many of the soils of the Lower Mainland and Vancouver Island were also acid in their virgin state. Since little historical account has been kept of soil pH values, it is not known what proportion of the land was acid before cultivation and what

Fig. 2. Percentages of acid soils (pH≤6.0) for cultivated land in agricultural areas of B.C.

proportion has been acidified since cultivation.

There were about 350,000 ha of cultivated acid soils with pH $\leq$ 6.0 in B.C. in 1978 (Table 4). About 160,000 ha of these acid soils are in the Peace River area. Most of those soils are in the pH 5.1-6.0 range. A large proportion of the soils in the North Central area are also acid, amounting to 95,000 ha, and as in the Peace River area, most of them are in the pH 5.1-6.0 range. Acid soils in the Okanagan are mainly in the fruit tree orchards as a result of acidification by fertilizers and other orcharding practices. Acid soils also occur in orchards in the Creston area. In the Lower Mainland, 84% of the soils are acid, with 11,000 ha at pH $\leq$5.0 and 54,000 ha at pH 5.0-6.0. The proportion of acid soils are even higher on Vancouver Island, with a total of 22,000 ha.

Table 4. *Estimated amounts of cultivated land in different soil pH ranges for several agricultural areas in B.C. — 1978

	Hectares			
Agricultural area	pH $\leq$5.0	pH 5.1-6.0	pH 6.0-7.0	pH >7.0
Vancouver Island	2,500	19,250	1,500	0
Lower Mainland	10,750	54,000	11,250	1,000
**Okanagan	1,000	3,000	4,000	4,000
North Central	500	94,000	59,000	24,500
Peace River	9,000	152,000	218,000	26,000
Total	23,750	322,250	293,750	55,500

* Estimates based on percentages of acid soils multiplied by hectares of cultivated land.

** Orchard soils only.

The trend is for an increase in acid soils in B.C. This was indicated by soil samples submitted for diagnostic purposes by farmers in 1978 compared to samples submitted in 1967 (Table 5). Little or no lime had been used during that time in the Peace River and North Central areas, but the pH trend was also downward in other areas even though liming was practiced.

Forestry

Generalized soil pH maps for B.C. show that the soils have pH less than 5.5 in most parts of the forested area of the province except for an extensive area of neutral and alkaline soils in the Central Interior stretching

from the U.S. border to Vanderhoof. The pH value of these soils are largely the result of natural development.

Fertilizers are not used in sufficiently large quantities in B.C. forests to likely cause an appreciable reduction in soil pH. Acid precipitation is also not likely causing acidification of forest soils with the possible exception of the southern coastal areas and relatively local problem areas.

Table 5. Changes in percentages of land in acid pH ranges for several agricultural areas in B.C. from 1967 to 1978

	Percentage of land in soil pH ranges			
	pH $\leq$ 5.0		pH 5.1-6.0	
Area	1967	1978	1967	1978
Vancouver Island	4.3	10.9	60.7	83.0
Lower Mainland	5.9	13.9	62.6	70.2
Okanagan	0.0	4.6	5.4	16.9
North Central	0.4	0.3	32.9	52.8

REMEDIAL

Correcting the Causes

The acid forming ammoniated fertilizers can be replaced by nitrate fertilizers containing a basic cation. The most common of these fertilizers are calcium nitrate and potassium nitrate. Unfortunately they have low N content and because of greater shipping charges per Kg of N, they are more expensive than the ammoniated fertilizers. For many farming systems, it is more profitable to use acid-forming fertilizers in conjunction with liming.

Several options are available for reducing the emissions of sulphur and nitrogen oxides into the atmosphere, which later causes acid precipitation. The conservation of energy and consequent reduction in use of fuels is an option. Use of alternative energy sources that are renewable would reduce emissions. High stacks have been used to carry emissions away from source but unfortunately transfer them to other areas. Probably the most effective short-term solution for sulphur dioxide emissions is the use of scrubbers in stacks (Overrein 1977). For motor vehicles, emission of nitrogen oxides can be reduced by use of devices such as EGR (exhaust gas recirculation valves) and the burning of unleaded gasoline.

Contending with Acidified Soils

There is a high variability in sensitivity of plants to soil acidity and thus the growing of tolerant crops might be considered an alternative to liming. However, growing of tolerant agronomic crops might be counter productive because the soil would become more acid in the meantime and eventually even the more tolerant crops could not be grown profitable. Grasses are generally much more tolerant to soil acidity than legumes (Hoyt et al. 1974). Of the legumes, red clover and alsike clover could be substituted for the much more sensitive crop, alfalfa. Among the grain crops, oats are the most tolerant, barley the least.

Liming is the best long-term solution in agriculture for contending with soil acidity. The feasibility of the use of lime is dependent on its cost. The cost has been too high in the Peace River area until recently, because of the difficulty of introducing supply and demand together. In that area, the cost of applied lime has been estimated to be $30 to $40/tonne when use becomes commensurate with need (Hoyt et al. 1981).

In the Okanagan, liming is a general practice and many sources of lime are being used, including a byproduct (mostly calcium carbonate) from packing houses. Ground limestone (calcitic) is also being used and, more recently, dolomitic lime is gaining popularity, partly because it also supplies Mg, which is generally deficient for tree fruit production. The cost of calcitic and dolomitic lime varies from $50 to $60/tonne in the Okanagan. Much of the lime is applied on top of the ground,without incorporation, because of possible tillage damage to the tree roots. However, Neilsen et al. (1981) reported that lime, as calcium hydroxide, applied to the top of the ground did not move beyond 10 cm deep in a Kelowna orchard soil in 5 years. Thus, there is a great need to find means to move the lime downwards into the soil.

Liming practices have long been established in the Lower Mainland and on Vancouver Island. In the Lower Mainland, the organic soils are limed when their pH falls below 5.0, delta soils are limed to keep pH at about 5.5 while the soils developed on glacial till are limed to keep their pH above 6.0 (R. Bertrand, Soils Branch, B.C. Ministry of Agriculture, Cloverdale, B.C., personal communication). On the Lower Mainland and Vancouver Island, 30,000 to 45,000 tonnes of lime are used annually. Most of it is calcitic lime.

Liming of forest soils is much more expensive than that of agricultural soils because of limited access for vehicles within the forest. Little or no

lime has been applied to B.C. forest soils.

REFERENCES

Bache, B.W. 1980. The acidification of soils. pp. 183-202 in T.C. Hutchinson and M. Havas, eds. Effects of acid precipitation on terrestrial ecosystems. Plenum Press, New York, N.Y.

Baker, J. 1977. Observations on nutrient levels in rainfall, lodgepole pine foliage, and soils surrounding two sulfur gas extraction plants at Strachan, Alberta. pp. 138-153 in H.S. Sandhu and M. Nyborg, eds. Proceedings Alta. Sulphur Gas Res. Workshop III. Alberta Environment.

Environment Canada. 1981. Acid rain: The forecast for western Canada, Edmonton, Alberta.

Fisher, A.G., Eaton, G.W. and Porritt, S.W. 1977. Internal bark necrosis of Delicious apple in relation to soil pH and leaf manganese. Can. J. Plant Sci. 57:297-299.

Gasser, J.K.R. 1973. An assessment of the importance of some factors causing losses of lime from agricultural soils. Expl. Husb. 25:86-95.

Holowaychuk, N. and Lindsay, J.D. 1982. Distribution and relative sensitivity to acidification of soils; Sand River Area, Alberta. Prep. for the Research Management Division Alberta Environment, and Canadian Petroleum Association. RMD Report 82/13.

Hoyt, P.B., Nyborg, M. and Penney, D.C. 1974. Farming acid soils in Alberta and northeastern British Columbia. Can. Dept. Agric. Publ. 1521.

Hoyt, P.B., Nyborg, M. and Ukrainetz, H. 1981. Degradation by acidification, pp. 41-71 in agricultural land, our disappearing heritage. A Symposium Proceedings of the 18th Alberta Soil Science Workshop. February, 1981, Edmonton.

Hoyt, P.B. and Hennig, A.M.F. 1982. Soil acidification by fertilizers and longevity of lime applications in the Peace River region. Can. J. Soil Sci. 62:155-163.

Johnson, A.H., Siccama, T.C. Wang, D., Turner, R.S. and Barringer, T.H. 1981.

Recent changes in patterns of tree growth rate in the New Jersey pinelands: a possible effect of acid rain. J. Environ. Qual. 10:427-430.

Katz, M., Wyatt, F.A. and Atkinson, H.J. 1939. in Effect of sulphur dioxide on vegetation. Nat. Res. Council Can. 815:131-164.

Nikleva, S. 1982. Progress Report to Western LRTAP Committee on AES Pacific Region Program. "Unpublished Manuscript", Environment Canada, Vancouver.

Neilsen, G.H., Hogue, E. and Drought, B.G. 1981. The effects of surface-applied calcium on soil and mature Spartan apple trees. Can. J. Soil Sci. 61:295-302.

Nyborg, M. and Walker, D.R. 1977. An overview — The effects of sulphur dioxide emissions on the acidity and sulphur content of soil. pp. 165-195 in H.S. Sandhu and M. Nyborg, eds. Proceedings Alta. Sulphur Gas Res. Workshop III. Alberta Environment.

Overrein, L.N. 1977. Acid precipitation — Impacts on the natural environment. pp. 1-26 in H.S. Sandhu and M. Nyborg, eds. Proceedings Alta. Sulphur Gas Res. Workshop III. Alberta Environment.

Pierre, W.H. 1933. Determination of equivalent acidity and basicity of fertilizers. Ind. Eng. Chem. Anal. Ed. 5:229-234.

Wang, C. and Coote, D.R. 1981. Sensitivity classification of agricultural land to long-term acid precipitation in eastern Canada. Land Resource Research Institute, Agriculture Canada. Contribution No. 98.

DEGRADATION EFFECTS OF SOIL ORGANIC MATTER LOSS

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INTRODUCTION

Soil is a living body, and all life in the soil depends, to varying degrees, on organic matter for energy and nutrients. Organic matter is the general term for a great variety of organic materials, representing different stages of decomposition. The final organic product of the decomposition process is humus, which is the most stable component of soil organic matter.

The process of decomposition involves both the degradation of plant constituents and the formation of new, more resistant materials, through microbial synthesis, and probably also through reactions catalysed by free enzymes. It is important to recognize that different soils contain varying proportions of different kinds of organic material.

To assess the significance of decreased soil organic matter levels (i.e. soil degradation), it is necessary to understand the influence of these materials on soil properties. The role of humus is especially important since this material is more stable (and therefore more persistent than) other organic components.

Improved structure can have a variety of beneficial effects, including reduced erosion, improved seedling emergence, improved infiltration and decreased runoff, and better aeration. Since these types of material are relatively easily degraded by soil micro-organisms, the benefits listed

above can only be sustained if there is a continued production of these constituents in the soil system.

In terms of soil chemical properties, humus makes substantial contributions. Humus constitutes the major reserve of nitrogen and sulphur in most soils and also contains a substantial fraction of the total phosphorus in surface soils. In the case of N and S, these nutrients can be subject to major leaching losses if not retained largely in an organic form, with mineralization occurring slowly over time. However, the N content of soil organic matter in general, and to a lesser degree of humus, can vary considerably as reflected in variations in C/N ratio. In some cases the C/N ratio is wide enough (>20) that the rate of N mineralization may be too slow to keep up with crop requirements. Thus the kind of organic matter, as well as its amount is important in determining soil behaviour.

Another extremely important contribution of humus is to nutrient retention through cation exchange. The cation exchange capacity (CEC) of humus is substantially higher than that of any of the clay minerals, and in humid regions, or under irrigation, the potential for leaching losses of nutrient cations like Ca^{++}, Mg^{++}, NH_4^+, and K^+ will be high in the absence of humus, unless sufficient CEC is provided by the clay fractions. For example, on coarse textured soils in the Lower Fraser Valley, heavy leaching losses of fertilizer nutrients might be expected if organic matter levels were not maintained.

Humus also plays an important role in forming rather stable complexes, such as chelates, with a number of micronutrients and also with aluminium.

The consequences of such reactions are largely dependent on whether the organic complexing agent (ligand) is insoluble (usually high molecular weight), or soluble and hence mobile in the soil system. With an insoluble ligand, chelation will lead to decreased availability of the complexed metal. In the case of essential micronutrients like copper, this would be an undesirable effect. On the other hand the tie-up of Al in an acid organic soil will decrease the risk of Al toxicity. However in most mineral soils, particularly those of high pH, chelation of micronutrients like Cu, Zn and Fe by low molecular weight ligands, probably enhances their availability to plants. In some situations chelation can also reduce toxicity of undersirable metal pollutants such as nickel, lead or excess Zn.

MAINTENANCE OF ORGANIC MATTER LEVELS

The question of whether organic matter levels will increase, decrease or remain steady over time, is basically determined by the balance between the annual rate of production or introduction of new organic matter and the rate of decomposition of organic materials to simple inorganic products like CO_2 and water. In an agricultural soil this balance is essentially controlled on the one hand by the amount of crop biomass produced and not removed from the site, and on the other hand by factors that influence decomposition rates as well as those influencing physical removal of topsoil through erosion. Of course organic matter inputs can also be affected by addition of organic amendments such as animal manures. Management will influence inputs through crop selection, maintenance of

fertility and a suitable moisture regime, and additions from external sources as well as by maximizing the return of crop residues. Management can minimize losses through controlling factors that tend to accelerate decomposition, especially by avoiding excessive tillage which leads to more exposed surface area of organic materials and greater access of oxygen for oxidative decomposition. Clearly, erosion losses must also be controlled.

Overall decomposition rates are largely controlled by climatic factors, together with other factors influencing microbiological activity. Since conditions favoring the latter are to a large extent the same as those favorable for crop production, the manager has less ability to control decomposition rates than he has for modifying inputs. The most effective approach to maintaining, or indeed raising organic matter levels, is to ensure maximum crop production, particularly of root material, which will maximize the return of crop residues and in turn will produce new humus. Fortunately this approach is entirely consistent with good soil and crop management practices.

The level at which organic matter can reasonably be maintained depends on a variety of considerations. Higher temperatures increase decomposition rates, making it harder to maintain high organic matter levels. In drier areas, where leaching losses are not expected, the contribution to CEC by the humus is of less significance. In heavy clay soil, when structure and water management problems are acute, it may be necessary to aim for higher organic matter levels. Basically the decisive factors which will provide

an answer to this question are soil type, climate, crops produced and erosion hazards.

Take the example of an average Lower Mainland dairy farm: 100 cows on 65 acres of land located on the Sumas Prairie. Most of the land is on continuous corn for silage. A very small portion of the crop residue is returned to the soil. There is heavy application of chemical fertilizers, diligent land preparation such as plowing, discing and harrowing for seedbed and weed control. Before long, the surface soil becomes virtually structureless. A plow pan forms and the expensive subsurface drainage system seems to stop functioning. As a result, crop yield declines. Neither the farmer nor the cows are happy. These are the typical symptoms of exhausted farmland.

Since it is not economical to leave the land in fallow, the only alternative to maintain this land's productivity is to continuously add organic matter (O.M.) to improve the physical properties. Farm manure is a handy material and is being applied in almost all the corn fields in the Fraser Valley. Green manuring is another popular method of increasing soil O.M. Alfalfa does not grow very vigorously in the Valley, but red clover and fall rye usually do well in most areas during most winters. The ideal green manuring crop for the Lower Mainland is a deep rooting, vigorously growing and low C/N ratio legume which loves our wet soils and mild winters. This kind of crop is yet to be found or to be developed by Crop Specialists.

Along the shallow continental shelf of B.C.'s Pacific coast there is one promising natural resource. Kelp, the giant seaweed. Kelp contains various kinds of mineral nutrients. It is also rich in enzymes and alginic acid $(C_6H_8O_6)_n$ and its sodium salt. When incorporated into soil, the enzymes may stimulate microbial activity and sodium alginate is known to be an excellent aggregate stabilizer. Both the B.C. Ministry of Environment and the Soils Department at U.B.C. are conducting research projects to study the cultivation, handling and application techniques of kelp.

CONSEQUENCES OF ORGANIC MATTER LOSS.

In relation to the theme of this workshop, the consequences of soil degradation in terms of decreasing organic matter content are indicated in the earlier discussion, and can clearly be serious. Many factors such as lower nutrient retention, lower water retention, increased erosion hazard, poorer structure and lower nitrogen reserves, can, depending on the soil type and climate, lead to lower productivity and/or increased cost of production. If the process is allowed to go too far, agricultural production may no longer be feasible at all, a scenario which is unacceptable in a Province with such a limited agricultural land base.

THE EXTENT OF SOIL DEGRADATION IN B.C.

As indicated already, we have a good understanding of the kind of problems that can arise in B.C. soils, and quantitatively we can be confident that some degradation has occurred, particularly with respect to

decreasing organic matter contents in many of our soils. However we have no information on changes in the quality of organic matter in soils under agricultural production, since such analyses are rarely undertaken. With respect to the quantitative aspect, the authors have been unable to locate any published data on how much degradation has occurred in B.C. soils, either with respect to the magnitude of decreases in organic matter levels of soils under agricultural production or on the resulting loss of productivity or increased cost of production. Such information is essential to evaluate the seriousness of such problems.

DEGRADATION EFFECTS OF SOIL COMPACTION

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My task at the workshop was a horrendous one. Within the time span of 15 minutes I was to discuss for all of British Columbia[1]:

-- "Causes of soil compaction. Identify and describe".

-- "Effects of soil compaction: some results, illustrations, effects on crop production".

-- "Assessment of the problem for B.C. Location (show map of B.C.) extent (how many hectares affected; as percentage of total agricultural land), rating of problem for the different locations, on map (e.g., severe, moderate, slight)".

-- "Suggested remedial measures, how to correct the problem".

When superimposed on the map of Europe, British Columbia stretches from the Mediterrenian to southern Sweden, and from Amsterdam to Prague.

I regret not having a better balance between Agriculture and Forestry. For the Peace River Region, the Central Region, the Okanagan and The Lower Fraser Valley my remarks will be in the context of agriculture. For the Cariboo and Vancouver Forest Regions the context will be forestry. The Prince George, Smithers, Kamloops and Nelson Forest Regions are not included.

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[1]Letter to the author re "B.C. Soil Degradation Workshop" from Laurens J.P. van Vliet, Agriculture Canada, Chairman, B.C. Soil Degradation Workshop Committee.

I am thankful to the contact persons who supplied me with information. Their names are included with each region.

My oral presentation was slide-based. I shall begin my written presentation with a discussion of relevant soils information. For all the regions except the Lower Fraser Valley I shall follow the slides. Additional information is presented on Lower Fraser Valley soils because of the research we have done on their physical and hydrologic behaviour.

I. BACKGROUND SOIL INFORMATION

A. Soil Hydrology (The terminology follows that used in "Application of Soil Physics, Hillel, 1980[b])

The cyclic relationship between soil strength, compaction, infiltrability, ponding, soil water content and tension, and back to strength can be seen in Fig. 6.

Soil compaction is accompanied by a reduction of the soil's infiltrability, which is a measure of the ability of the soil profile to conduct water when it rains. Infiltration is the process of water movement into the soil across the soil surface. When the rainfall rate is equal to the just ponding rate the infiltration rate is profile-controlled and is equal to the soil's infiltrability. Just ponding is the hydrologic condition where the rainfall and infiltration rates are balanced in such a manner that a thin layer of free water is maintained on the soil surface. An increase of the rainfall rate above the just-ponding rate, and therefore above the soil's infiltrability, causes overland flow on sloping land and ponding on horizontal land. When the rainfall rate is below the just-ponding rate the infiltration rate is rainfall-controlled and equal to

the rainfall rate. Thus, the infiltrabiltiy is the upper limit of the rainfall-controlled infiltration rate.

Under conditions where rain is falling at the just ponding rate on an initially dry soil the infiltrability is maximum at the start of the rainfall event. As the rain continues, the infiltrability decreases to a minimum, called the steady state infiltrability. The decrease is due to both a decrease of the force that pulls water into the soil during a rainfall event, and to a change of soil surface structure that results from the beating action of falling raindrops.

Steady state is the condition where the downward flow rate of water is constant with depth and equal to the rainfall rate, and where the watertable is stationary. The steady state infiltrability is related to the satiated hydraulic conductivity of the least permeable layer or horizon in the soil profile. The satiated hydraulic conductivity is lower than the saturated conductivity because of air entrapment.

The ideal hydrologic condition exists when all the rainwater infiltrates as it falls, that is, when the infiltration rate is rainfall-controlled. Thus, the ideal hydrologic condition will exist as long as the infiltration requirement is met (Fig. 1).

In Fig. 1 the infiltration requirement is set equal to the prevailing rainfall rate for the area under consideration. For example, a reasonable value for the Lower Fraser Valley is 1 mm/h. There is no ponding/overland flow when a soil's steady state infiltrability is above the infiltration requirement, that is, when the ideal hydrologic condition is maintained. However, water will pond and there will be overland flow on

Steady State Infiltrability mm/h	
100	well-managed Lower Fraser Valley silty clay lowland soil
10	
1	infiltration requirement = prevailing rainfall rate
0.1	poorly managed Lower Fraser Valley silty clay lowland soil

Fig. 1 Infiltration Requirement for the Lower Fraser Valley

the poorly managed soil because its steady state infiltrability is below the infiltration requirement.

Management Recommendation

> To prevent ponding and overland flow soils must be managed in such a manner that the steady state infiltrability is at least one order of magnitude above the infiltration requirement.

B. Soil Trafficability and Soil Strength (for a discussion of soil strength see "Fundamentals of Soil Physics" Hillel, 1980[a])

The greatest cause of soil compaction in both agriculture and forestry is the operation of machinery and the grazing of livestock under conditions where the soil is not trafficable. A soil that is trafficable has sufficient strength to support traffic of machinery and/or livestock without compaction taking place beyond limits of root growth and infiltrability. The relationship between soil strength and trafficability is discussed elsewhere (Paul and de Vries, 1979[b]).

Soil compaction results in an increase in bulk density (kg of solids per m^3 of bulk soil) and a corresponding reduction in the porosity (m^3 of pores per m^3 of bulk soil). Porosity reduction occurs mostly at the expense of the aeration porosity (m^3 of aeration pores per m^3 of bulk soil). Aeration pores are large pores that drain at soil water tensions below 0.60 m of water.

The relationship between soil strength and soil water tension can be seen in Fig. 2 for a Lower Fraser Valley lowland soil. Fig. 2 shows

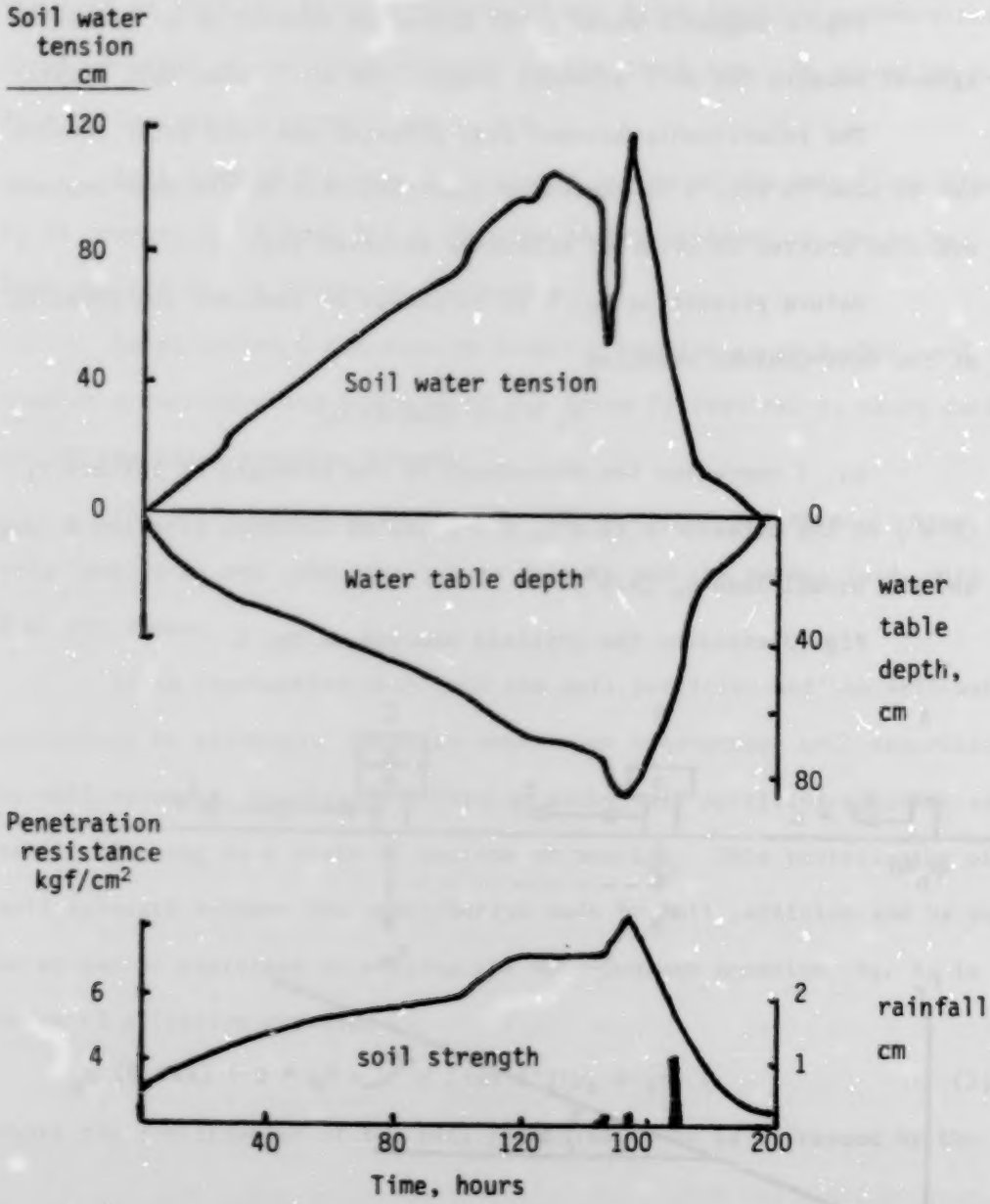

Fig. 2--The relationship between watertable depth, soil water tension and soil strength for the ploughlayer of a Lower Fraser Valley lowland soil (Paul and de Vries, 1979[a]).

that as the water table was lowered over time, both soil water tension and strength increased. After 160 h of drainage the water table was brought back to the surface, and both water tension and strength decreased to zero.

Fig. 2 suggests water table elevation control as an effective management measure for soil strength control for soils that have a water table.

The relationship between soil strength and soil water tension that can be seen in Fig. 2 is expressed quantitatively by the Mohr-Coulomb equation written in terms of effective stresses (Eq. 2).

Before presenting Eq. 2 it is useful to consider the physical basis of the Mohr-Coulomb equation

$$F_f = c + (\tan \emptyset)\, \sigma_n \qquad (1)$$

Eq. 1 expresses the dependence of the strength at failure F_f (N/m^2) on the cohesion c (N/m^2), the angle of internal friction $\emptyset$ (degrees) and the normal load σ_n (N/m^2).

Fig. 3 explains the physical meaning of Eq. 1

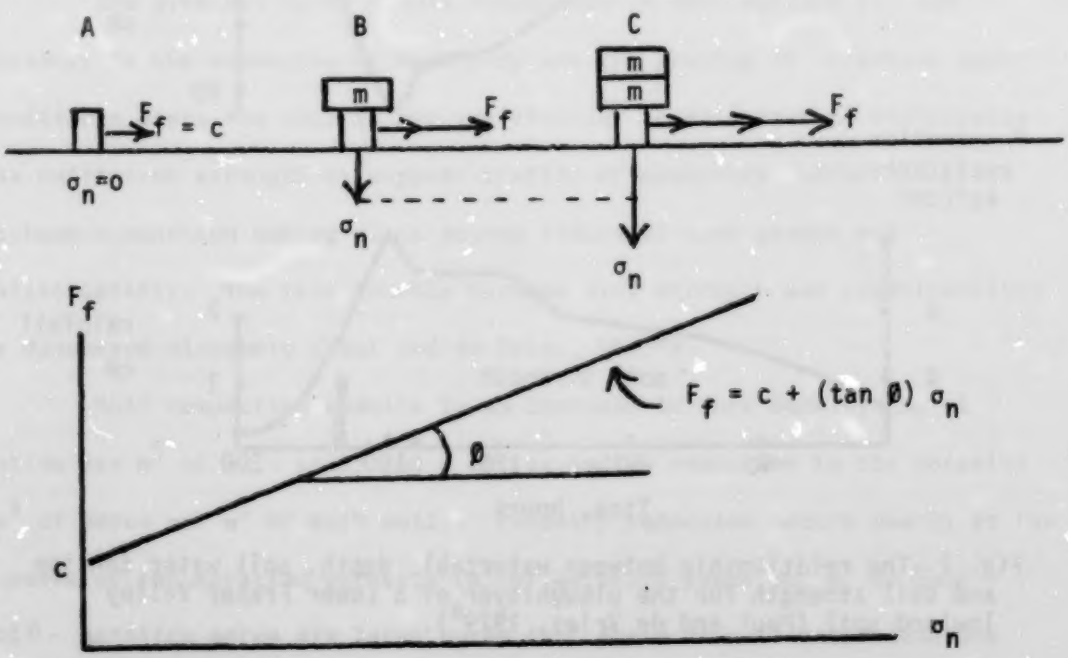

Fig. 3--The physical meaning of the Mohr-Coulomb equation.

In situation A, in Fig. 3, a block of wood is placed on a laboratory bench top and the force F_f to cause it to just move is measured. The block is assumed to be weightless. F_f is called the strength at failure, because failure of the block-benchtop system occurs at first movement of the block relative to the bench top. In situation A, $F_c = c$, because the normal load $\sigma_n = 0$.

In situation B a mass m is placed on top of the weightless block. F_f is greater for B than for A, because of the presence of the normal load related to the weight of the mass m.

In situation C the mass is doubled, causing σ_n to double, and causing a corresponding increase in the force F_f required to cause failure of the block-benchtop system.

The Mohr-Coulomb equation (Eq. 1) expresses the straight-line relationship between the strength at failure and the normal load, with tan ϕ as the slope.

In an unsaturated soil both the soil particles and the soil water contribute to strength. Water present in an unsaturated soil contributes to soil strength, in that it literally sucks soil particles together as a result of being in a state of suction or tension. This partitioning of soil strength between the contribution made by soil particles and by soil water can be expressed by writing the Mohr-Coulomb equation, Eq. 1, in terms of effective stresses

$$F_f = c' + (\tan \phi')(\sigma_n + \chi\tau) \qquad (2)$$

where the contribution of the soil particles to F_f is expressed by the

effective cohesion c', and the effective angle of internal friction Ø', and the contribution of the soil water by $\chi\tau$, where $\chi = 0.82$, a constant related to the degree of saturation, and τ is the soil water suction or tension (N/m^2). With respect to the contribution of soil solids to soil strength, clays derive their strength mainly from c' and sands from Ø' and most soils from both c' and Ø'. In a pure sand Ø' is related to the angle of repose: the more angular and rougher the sand particles, the larger the angle of repose, and the larger Ø'. Thus, for the construction of a sand playfield it is advantageous to select a sand with a large Ø', or a sand that has grains that are angular and that have a rough rather than smooth surface.

Fig. 2 and Eq. 2 show that the higher the soil water tension, the stronger the soil. For upland soils, maintenance of the infiltrability at the highest possible value is the most practical management method of maximizing soil water tension, and therefore strength and trafficability, during the critical spring cultivation and late summer/fall harvest periods. For lowland soils (soils that have a watertable) water table elevation control is the most effective management method of maximizing trafficability.

C. Soil Workability

A soil is workable when its cultivation produces a soil of good tilth, or a soil that is in good physical condition in its relation to plant growth (Baver et al., 1972).

Medium and fine textured soils are workable at water contents below the plastic limit and within the friable consistency range (Fig. 4).

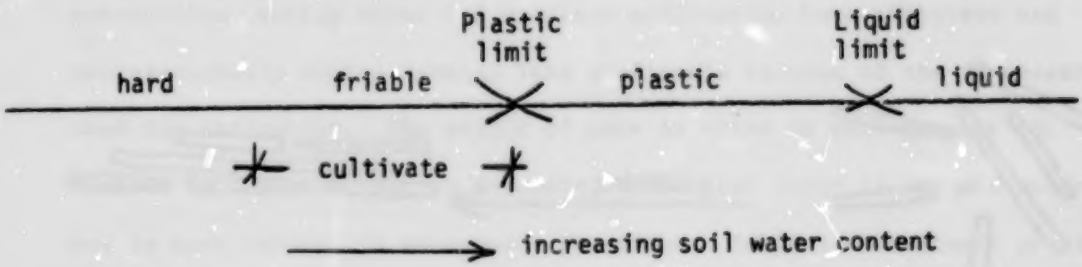

Fig. 4--Soil consistency scale.

Within the plastic range medium and fine textured soils will deform in response to the application of a force, and will retain their shape when the force is removed. Thus, in the plastic range these soils are mouldable. In contrast, within the friable range these soils will fracture in response to manipulation, and break up into smaller structural units.

Driving on or cultivation of medium and fine textured soils at water contents above the plastic limit results in puddling. Puddling is defined as the change in orientation of disc-shaped clay particles from random in the the undisturbed soil to parallel in the puddled soil in response to manipulation at water contents above the plastic limit (Fig. 5).

An undisturbed silty clay soil may have a steady state infiltrability ('K'_s) as high as 100 mm/h, whereas the 'K'_s of the puddled soil may be as low as 0.1 mm/h.

In general, a soil becomes workable at a higher tension than the tension at which it becomes trafficable. Thus, a soil that is trafficable is not necessarily workable.

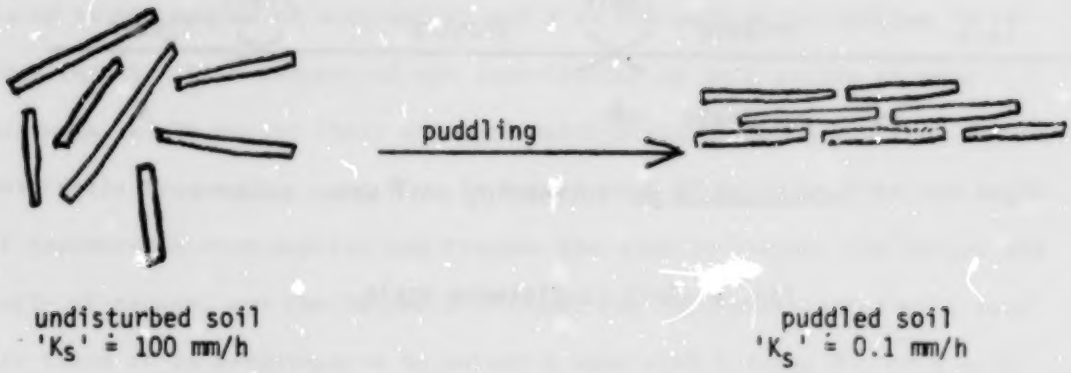

Fig. 5-- The process of puddling.
'K_s' = steady state infiltrability.

D. Effects of Soil Compaction

The effects of soil compaction are three-fold.

First, compaction affects soil hydrologic behaviour in that it affects the manner in which rainfall is partitioned at the soil surface between infiltration and ponding/overland flow. One of the objectives of soil management is the maintenance of infiltrability well above the infiltration requirement (Fig. 1), thereby preventing ponding on horizontal land and overland flow on sloping land.

Second, soil compaction affects plant growth. A compacted surface layer or crust interferes with and sometimes prevents seedling emergence.

A compacted subsurface layer or pan tends to interfere with root penetration, making water and nutrient utilization less efficient and correspondingly making farming less profitable because of the increased need for irrigation. The origin of pans is often in part genetic (Bt horizon in luvisols, Bnt in Solonetz, dense peat layer in organic soils), and in part related to management practices. In fact, management practices often aggravate the effects of a genetic pan. Pans are also called traffic pans or plough pans.

Third, compaction causes an increase in cloddiness of the Ap horizon. Cloddiness can cause seed-soil contact problems. It also reduces the efficiency of potato harvesting.

II. SOIL DEGRADATION EFFECTS BY COMPACTION IN THE REGIONS OF BRITISH COLUMBIA

A. The Peace River Regions. Contact persons Mr. Arnold Hennig, Agriculture Canada, Beaverlodge, Alta., and Mr. Jack Dobb, B.C. Ministry of Agriculture and Food, Dawson Creek, B.C.

In the Peace River Region 500,000 to 800,000 ha are in the solonetzic order and 1,000,000 ha are in the Luvisolic order.

1. Solonetzic Order

a) Inherent Problems

Inherent problems are related to the Bnt horizon and the shallow nature of the Ap horizon. The Bnt horizon exists in a dispersed state because of the high sodium concentration and correspondingly has a high bulk density (up to 1,600 kg/m^3) and a near-zero infiltrability (Toogood

and Cairns, 1973). These characteristics cause rainwater to perch on top of the Bnt horizon, saturating the Ap, causing ponding and overland flow.

b) Problems related to management.

Excessive and repeated cultivation to the same depth and cultivation and grazing at water contents above the plastic limit (Fig. 4) result in puddling, and tend to aggravate both the surface crusting problem and the Bnt-related pan problem.

c) Prevention and remedies for solonetzic soils. Prevention of compaction requires that a soil be cultivated only under conditions where its consistence is in the friable range (Fig. 4).

Remedial measures include continuous rotational cropping, with grasses and legumes included in the rotation, elimination of summerfallow, return of crop residues to the soil, and a periodic late fall deep chisel cultivation followed by a shallow spring cultivation. The depth of deep ploughing required to achieve the benefits that are possible depends largely on the thickness of the various soil horizons. The plough should penetrate the Csk horizon to a depth that will provide about a 1:1:1 mixture of Ap, Bnt and Csk horizon soil. (Toogood and Cairns, 1973).

2. Luvisolic Order

a) Inherent Problems.

Climate is probably the most important cause of soil compaction in the Peace River Region. This includes high intensity spring and summer rainfall events and the heavy snowpack in winter.

Inherent soil problems are related to the low organic matter content of the Ap horizon and the high bulk density and low infiltrability

of the Bt horizon. Inherent physical characteristics of Luvisolic Bt horizons are presented for two soils in Table 1 (Black et. al., 1982).

	Bulk Density kg/m^3	Infiltrability mm/h
Codesa sandy loam	1,600	2.5
Sloane fine sand loam (Bt: silty clay)	---	0.96

Table 1--B_t characteristics of two luvisols in the Peace River Region.

Rainfall intensities greater than 2.5 mm/hour are common for convective spring and summer rainfall events, causing perching of water on top of the Bt horizon.

b) Problems Related to Management

Problems related to management are related to clearing, breaking and cultivation taking place at water contents above the plastic limit, contributing to the Bt-related pan problem and causing cloddiness of the Ap horizon, as does too deep first breaking or too deep cultivation. Over-cultivation including that as a part of summerfallowing, leads to crusting, and cultivation when too dry leads to "pan surface polishing" and to cloddiness. Crust formation interferes with seedling emergence, and may contribute to overland flow and erosion because of the low infiltrability of the crust. Aggravation of the Bt-related pan problem (as a result of compaction) in turn aggravates the root penetration problem.

c) Prevention and Remedies

Compaction and soil crusting problems on Luvisols can be prevented by breaking and cultivating at soil water contents in the friable range, by

minimizing cultivation and reducing (eliminating?) summer fallowing, by continuous rotation cropping with grasses and legumes being included in the rotation, by returning crop residues to the soil, by gradually increasing cultivation depth and by leaving the seedbed in a lumpy rather than in a pulverized tilth. The seedling emergence problem can be overcome in part by using a heavier rate of seeding. Finally, contour cultivation would minimize overland flow and correponding water erosion problems and liming would help strengthen the structure of the Ap horizon.

B. The Central Region. Contact person Mr. Robert Kline, B.C. Ministry of Agriculture and Food, Prince George, B.C.

Remarks made with respect to Luvisols of the Peace River Region also apply to the Luvisols of the Central Region.

Hectarages of cultivated land are presented in Table 2.

	Cultivated
Fraser Fort George	4,400 ha
Bulkley Nechako	10,500
Kitimat Stikine	700
	15,600 ha

Table 2--Areas of cultivated land in the Central Region

The 15,600 ha comprise 12% of improved farmland. About one third of all cultivation events are conducted under conditions where the soil water content is above the plastic limit. Therefore, compaction is taking place on 10 to 30% of 15,600 ha or on 1,600 to 4,700 ha.

C. The Cariboo Forest Region. Contact person Mr. Bill Watt, B.C. Ministry of Forests, Williams Lake.

Tables 3, 4 and 5 give an impression of the severity of the compaction problems.

Productive forest land ha	Harvested annually ha	Compacted area ha	Annually % of harvested	% of productive
6,000,000	30,000	3,000 to 6,000	10 to 20	0.05 - 1.0

Table 3--The extent of the compaction problem in the Cariboo Forest Region

The data of Table 3 show that "a slow erosion of the resource is taking place."

1. Fraser Plateau

The soils of the Fraser Plateau are medium to fine textured luvisols, generally with a loam Ae and a clay loam Bt horizon. Harvesting vehicles being operated under conditions where the soil is not trafficable is a major cause of soil churning and compaction. The data of Table 4 show that this churning is accompanied by an increase in the soil's bulk density.

Location	Depth	Bulk Density Kg/m3 Undisturbed	Landing	Ripped Landing
South of Williams Lk.	0-0.15	1,360	1,710	1,440
	0.15-0.30	1,450	1,940	1,880
	0.30-0.60	1,810	2,140	1,920

Table 4--Compaction of a Fraser Plateau Forest Soil

In the most severe case one half of a 100 ha block was disturbed and compacted.

The change in harvesting technology to larger and heavier equipment leading to increased soil compaction is a worrying trend.

2. Quesnel Highlands

In the Quesnel Highlands the soils are generally Luvisols of coarse texture (micacious sands) and of very weak structure. Accordingly, they tend to erode easily. Tree harvesting tends to cause serious compaction, as shown by the data of Table 5.

	Bulk Density, kg/m^3
Undisturbed	660 - 1,280
Skyline Yarding Road	1,980 - 1,070
Skidroad (crawler)	1,690 - 2,130

Table 5--Compaction of a Quesnel Highlands Forest Soil

The bulk densities of Tables 4 and 5 are amongst the highest I have seen. The effect of compaction on regeneration is not known.

D. The Okanagan. Contact person Dave Stevenson, Agriculture Canada, Summerland, B.C.

Compaction is generally not a problem for the Okanagan orchard soils: "Farmers do not observe it"; "extension personnel do not report it"; "research people do not find evidence of it".

However, on the glacial till soils of the North Okanagan problems have been observed related to compacted sub-soils causing restricted root growth.

E. Vancouver Forest Region. Contact person T.M. Ballard, Department of Soil Science, University of British Columbia.

Less than 1 percent of the total area is compacted due to tree harvesting and site preparation. The highlead harvesting system, which is the prevalent system in the region, causes little compaction in the cut-over areas. However, localized compaction on landings is a serious problem.

Tractor logging is causing serious compaction problems on the east side of Vancouver Island.

The remedy is ripping of landings and tractor roads followed by seeding down of a grass-legume mixture.

F. Lower Fraser Valley

The data of Table 6 show that in British Columbia more than one half of the dollar value of farmsales is generated on less than one tenth of the B.C. area of improved farmlands. Within the Lower Fraser Valley lowlands comprise about 90 percent of the total area of improved farmlands.

	Improved farmland ha	farmsales $'s
Province	935,400	210,000,000
Lower Fraser Valley		
Total	80,200	115,000,000
Lowlands	73,000	

Table 6--Farmsales area of improved farmland for the province and the Lower Fraser Valley

1. Upland Soils.

In the Lower Fraser Valley upland soils are generally developed in glaciomarine or in aeolian parent materials. The glaciomarine soils tend to have naturally compacted and low infiltrability/root penetrability sub-soils. The aeolian soils are beautiful.

Serious management-related compaction is taking place on the upland soils, related to the mechanization of soft fruit production. This compaction is resulting in decreased infiltrability, and increased overland flow and water erosion[1].

2. Lowland Soils: entrapment in the vicious circle of wet soils and compaction; management methods of break-out and escape. Contact person Mr. Robert T. Reynolds, Farmer, West Delta.

The data base and interpretation for this section is our own (J. de Vries and graduate students Compton L. Paul, John Heinonen and Mensah Bonsu).

Parent materials of lowland soils are of flood plain, lacustrine, deltaic and organic origin. Their behaviour in terms of strength, trafficability and corresponding susceptibility to compaction is profoundly influenced by the presence of a high watertable.

During the off-season we have observed more than 90 percent of cultivated lowland fields to be partially ponded. Although we have not carried out a comprehensive survey, there is strong evidence that the pan problem parallels the ponding problem.

[1]Personal communication, B.C. Ministry of Agriculture and Food Personnel.

Specific field observations and measurements made by our group since 1975 indicate that on Lower Fraser Valley lowland soils a self-reinforcing process of soil degradation by compaction and puddling is at work[1]. The process is represented by the vicious circle of wet soils and soil compaction illustrated in Fig. 6, with the farmer-operator trapped inside. The mechanism of entrapment, legacies of entrapment, and practical management measures of escape are discussed below.

a) The Mechanism of Entrapment.

Fig. 6 shows that ultimately ponding is a legacy of itself. Ponding causes a loss of opportunity days and corresponding costly delays in spring. Using West Delta as an example, toward the end of March and in April there is a rush amongst farmers to get their land ready for planting/seeding of profitable cash crops such as potatoes and peas. In most springs cultivation starts on land that is the first to become trafficable because it is off-season drained. The spring of 1983 is a good example: in West Delta farmers on off-season drained land started planting early potatoes in March. Seeing cultivation begin on off-season drained land causes farmers whose land is not off-season drained to start work also, frequently as soon as ponded water has disappeared "to dry out the soil", and in some cases when ponded water is still present.

The practice of working the land when the soil is not trafficable/workable causes compaction and puddling, reduces infiltrability, increases the occurrence of ponding during the off-season

[1]On at least one occasion the author has heard a parcel of lowland being referred to as "junkland, that cannot be farmed profitably".

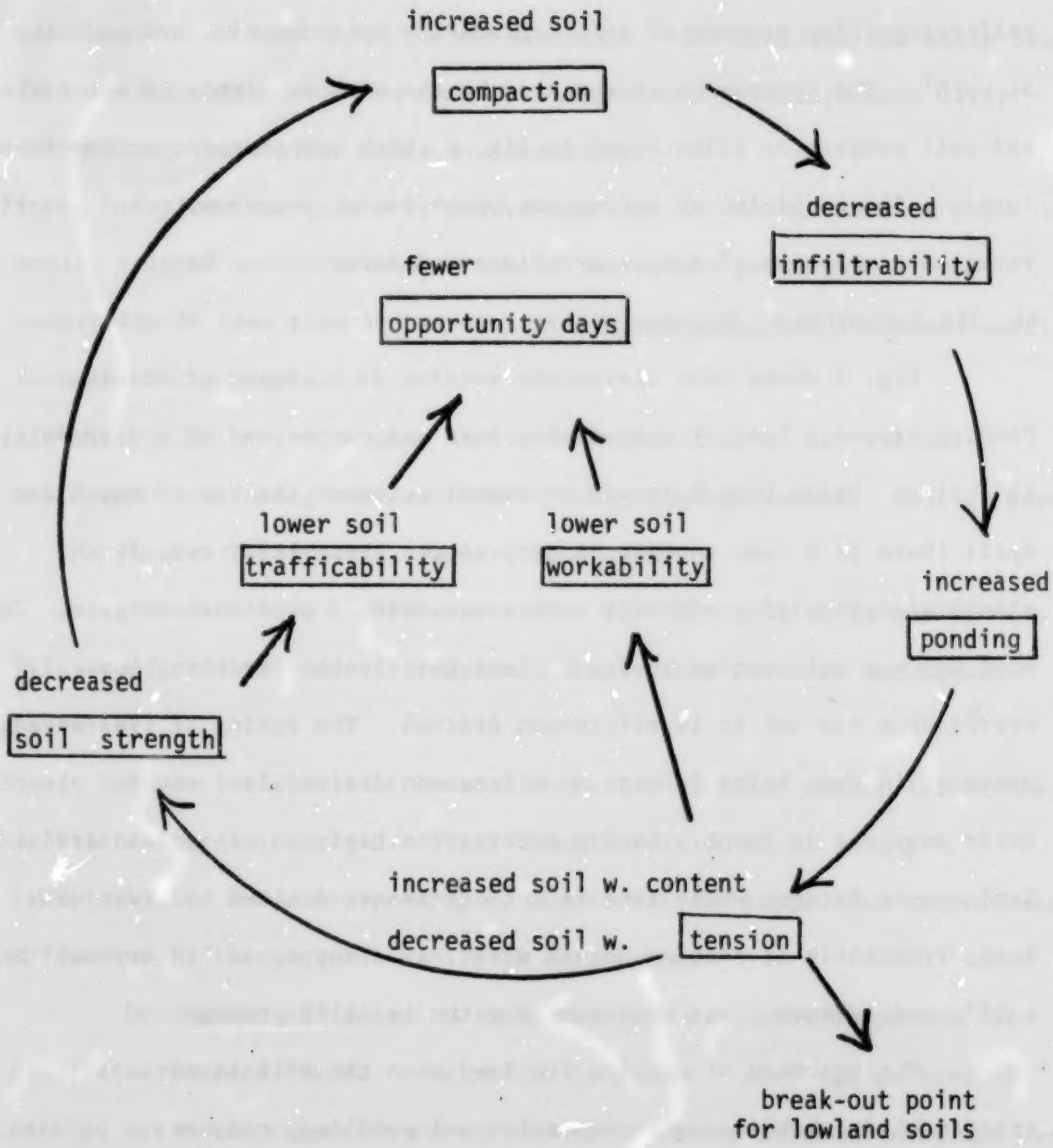

Fig. 6--The vicious circle of wet soils and compaction.

and in spring, and lateness of seeding/planting. Lateness of seeding/planting in turn causes lateness of harvest, with potatoes and silage corn often being harvested under marginal conditions in terms of trafficability because of fall rains. During the off season this land is left in a compacted, bare and ponded state, further worsening the ponding and corresponding delay problems the following spring.

Thus, lowland farmers whose land is not off-season drained end up being trapped within a vicious circle of wet soils and soil compaction.

b) Legacies of Entrapment

The formation of a low infiltrability surface layer, increased plough layer cloddiness and the formation of a pan are legacies of entrapment in the circle.

i) The mechanism of formation of the low infiltrability surface layer.

Our research has shown that the low infiltrability surface layer tends to form in depressions where free water tends to collect. This free water has two origins, flooding and ponding. Flooding is the condition where the water table has risen above the soil surface because of inadequate water table and drainage ditch water level elevation control. Ponding is the condition where free water is present on the soil surface, with the water table located below the soil surface, and with unsaturated soil being present between the surface and the watertable. Flooding occurs when the drainage requirement is not met, and ponding occurs when the infiltration requirement is not met (Fig. 1).

In depressional areas the low infiltrability surface layer consists of thin layers or rhythmites of sediment that has settled from the pond. The sediment has two sources. One source is erosion induced by overland flow on a concentric area immediately adjacent to the pond (Fig. 7).

Fig. 7--The mechanism of low infiltrability surface layer formation in a ponded depression.

A second source of sediment is erosion of the pond bottom induced by wind-driven wave action. After a rainfall-wind event the sediment settles to the bottom, forming a thin layer or rhythmite. Thus, during the off-season and spring months a low infiltrability surface layer is formed, about 1 cm thick, consisting of a number of rhythmites, each corresponding to a rainfall-wind event. The clay particles in the layer have a parallel orientation, and our measurements have shown it to have a steady state infiltrability of 1.8 mm/day, or about one order magnitude below the infiltration requirement of 24 mm/day.

We have simulated the mechanism of formation of the low infiltrability surface layer in the laboratory. This was done by creating a number of sedimentation events by allowing sediment to settle from suspension in increments on top of a layer of saturated sand of known saturated

hydraulic conductivity. The layer that was formed consisted of a number of rhythmites, each corresponding to a sedimentation event. The silty clay loam sediment was taken from a ponded depressional area on a lowland soil. The composite layer had a steady state infiltrability of 0.2 mm/h. The nearness of this value to the one measured in the field indicates that in ponded depressional areas soil degradation has reached its limit.

Ponding depths of 20 cm are common. In April evaporation rates vary up to 2 mm/day. Our measurements indicate that the hydraulic gradient across the surface layer is equal to about 10 cm/cm. Thus, water will infiltrate at a rate of q = K (water potential gradient) = (1.8)(10) = 18 mm/day, for a total recession rate of 20 mm/day. Thus, through the combined effect of infiltration (18 mm/day) and evaporation (2 mm/day) a pond 20cm = 200mm deep will disappear in about ten rainless days, causing a serious loss of opportunity days.

The formation of the low infiltrability surface layer can be avoided by preventing free water from ever being present on the soil surface. This can be done by meeting both the drainage requirement and the infiltration requirement (Fig. 1).

ii) Ploughlayer cloddiness.

Ploughlayer cloddiness is a second legacy. It tends to make seed-soil contact more difficult, necessitating the use of implements such as rotovators. It also reduces the efficiency of potato harvesting by increasing tuber loss during harvesting. Futhermore, cloddiness requires

hired people to ride on the harvester to pick clods from the stream of potatoes and in extreme cases potatoes from the stream of clods.

iii) Traffic pan formation.

A third legacy is pan formation. The research done by Söhne (1958) has shown that compaction extends to depths far below the bottom of the ploughlayer. Traffic pans typically occur at a depth of about 20 cm and are about 8 cm thick. They tend to restrict root growth, thereby reducing the efficiency of nutrient and water utilization, and increasing the need for irrigation, with a corresponding reduction in farm profitability. Furthermore, during the growing season we have observed water to perch on top of the pan, causing saturation of the ploughlayer and summerponding.

c) Management Measures of Escape from the Circle.

"The results obtained from experimental fields in the Netherlands show that the benefits of drainage are primarily attributable to its positive effects on tillage conditions and trafficability, rather than to any direct effect on crop production during the growing season. In fact very often a farmer's decision to drain his field is based entirely on avoiding problems of practical management during autumn and spring, when harvesting and tillage operations and grazing may be impeded because of water logging". (Kessler, 1979)

i) Water elevation control.

Recalling the relationship between soil water tension and soil strength (Fig. 2, Eq. 2), increasing soil water tension by lowering the

water table is the most practical method of escape from the circle. Thus, in Fig. 6 the compaction circle break-out point is located at soil water tension. After break-out and escape the farmer enters the soil improvement circle of Fig. 8: off-season drainage increases soil water tension and strength in spring, reduces soil compaction, facilitates increasing the infiltrability above the infiltration requirement by the growing of off-season cover crops for soil surface protection and structure improvement and through increased earthworm populations. The meeting of the infiltration requirement eliminates off-season ponding, resulting in higher soil water tension and greater strength in spring. The circle of Fig. 8 is now closed, and a self-reinforcing soil improvement process is set in motion.

ii) Off-season cover crops and earthworm management.

Off-season water table elevation control results in stronger and therefore more trafficable/workable soils in spring, allowing timely cultivation and seeding/planting. We assessed the effects of off-season drainage on trafficability of farmland over a two-year period. Our research has shown that when compared to undrained land, off-season drainage by drains spaced at 30.5 m resulted in earlier trafficability by 2-4 weeks in a silty clay loam and by up to 5 weeks in an organic soil (Paul and de Vries, 1983b). Timely seeding/planting leads to timely harvest in fall, leaving time for the planting and development of an off-season covercrop. For example, in West Delta chipping potatoes require 120 days between planting and harvest. The optimum planting time is May 4-15. However, when the

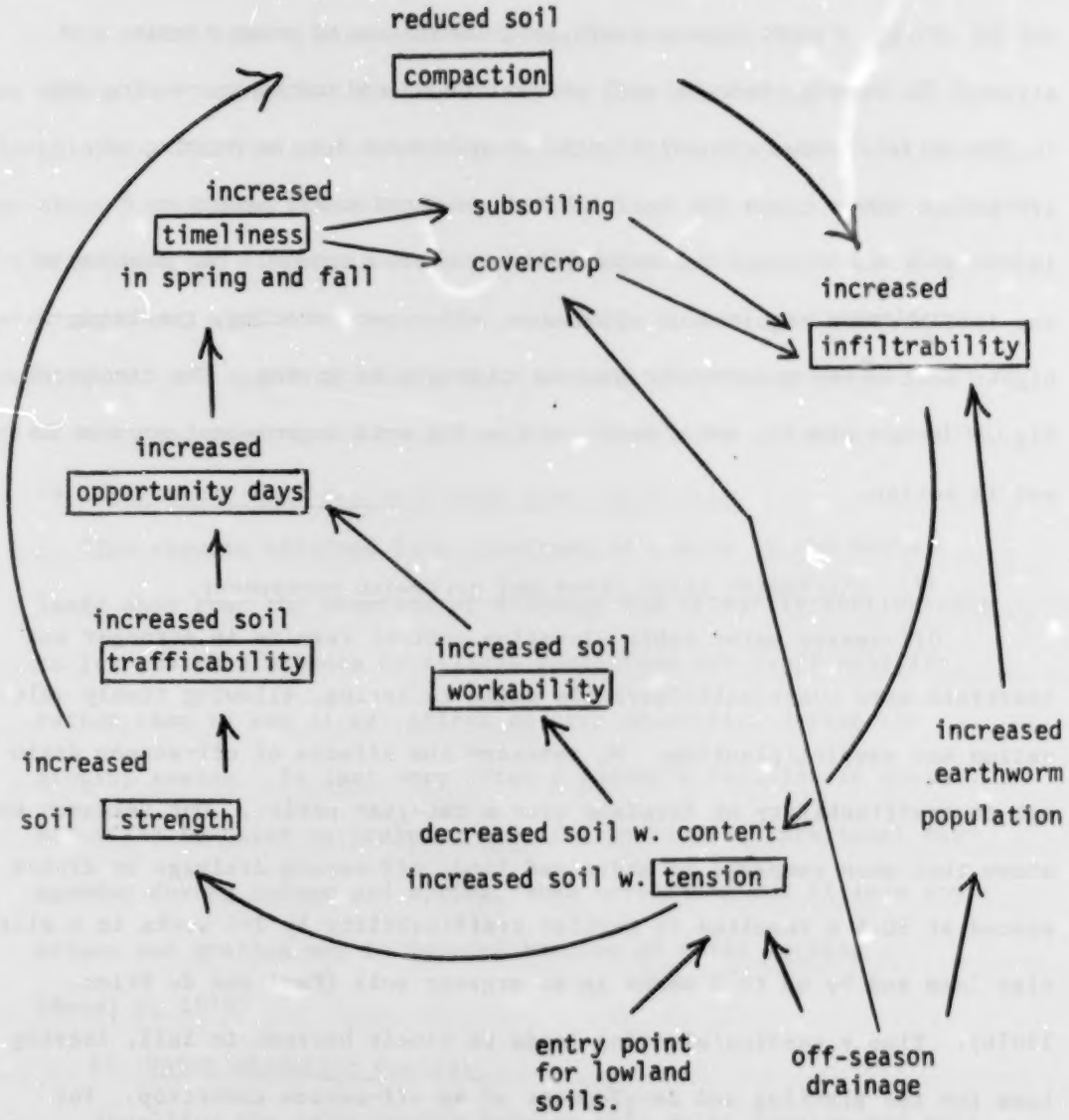

Fig. 8--The soil improvement circle.

weather is good, planting may start as early as April 23. Although rye is a suitable cover crop, barley is used by at least one producer (personal communication R.T. Reynolds). The optimum planting date for barley in terms of effectiveness is September 1, although it can be planted as late as October 1. It is broadcast-seeded with a fertilizer spreader, and may reach a height of about 35 cm. The barley plants are killed by frost and fall down, forming a continuous mat protecting the soil surface from the beating action of raindrops.

Furthermore, as a result of the maintenance of an aerated or unsaturated zone during the off-season, the earthworm population will increase. In an off-season-drained field during the red clover part of a 6-year rotation we have found an earthworm count of 640 earthworms per m^2, with a corresponding steady state infiltrability of 150 mm per hour. (Carter et al., 1982). In contrast, in an adjacent undrained field the earthworm population was 3 earthworms per m^2, with corresponding infiltrabilities of 0.1 mm per hour (in a depression) and 40 mm per hour (on higher ground). Most earthworm species are surface feeders and become active at temperatures above 6°C, temperatures which are common in the Lower Fraser Valley during the off-season. As the earthworms move to the surface to feed on the organic matter left by the barley, they leave channels perforating the soil surface, and increasing the soil's infiltrability up to three orders of magnitude above the infiltration requirement.

iii) Off-season manure spreading.

Off-season water table elevation control to meet the drainage requirement facilitates manure spreading. Many dairy farmers prefer to spread manure as it is produced because of the expense involved in the construction of manure storage facilities.

iv) Sub-soiling.

After a water table elevation control system has been installed sub-soiling is an effective method of pan elimination. It is good practice to dig a soil pit before starting the operation to establish the location of the pan. Also, it is essential that the sub-soiler's shovel be set just below the bottom of the pan so that it is shattered in place through a lifting action. Finally, sub-soiling should be carried out in late summer-early fall when the pan is brittle rather than plastic.

v) Regional water management.

Water table elevation control requires year-round pumped drainage ditches, in conjunction with regional water management. In areas such as the vegetable-producing Nicomekl-Serpentine Delta in Surrey, upland run-off management, including management of runoff originating from urbanized uplands, is an integral part of regional water mangement.

To summarize, for lowland soils,

Off-season water management (water table elevation control by means of sub-surface drainage and pumped drainage ditches) is a prerequisite for soil management.

Regional water management is a prerequisite for on-farm water management.

REFERENCES

Baver, L.D., Walter H. Gardner and Wilford R. Gardner. 1972. Soil Physics. John Wiley, Toronto.

Carter, Alan, John Heinonen and Jan de Vries. 1982. Earthworms and water movement. Pedobiologica 23: 395-397.

Hertzman, O., T.A. Black and C.H. Wallis. 1981. Pasture productivity and water balance in the British Columbia Peace River Region. Interim Contract Report to the Land Resource Research Institute. Agriculture Canada, Ottawa.

Hillel, Daniel. 1980. Fundamentals of Soil Physics. Academic Press. Toronto.

Hillel, Daniel. 1980. Application of Soil Physics. Academic Press. Toronto.

Kessler, J. 1979. Field Drainage Criteria in Drainage Principles and Applications. Theories of Field Drainage and Watershed Runoff. Publ. 16, Vol. II, Int. Inst. for Land Reclamation and Improvement/I.L.R.I. Wageningen, The Netherlands.

Paul, C.L. and J. de Vries. 1979. Prediction of soil strength from hydrologic and mechanical properties. Can. J. Soil Sci. 59: 301-311.

Paul, C.L. and J. de Vries. 1979. Effect of soil water status and strength on trafficability. Can. J. Soil Sci. 59: 313-324.

Paul, C.L. and J. de Vries. 1983. Soil trafficability in spring. 2. Prediction and the effect of subsurface drainage. Can. J Soil Sci. 63: 27-35.

Söhne, W.M. 1958. Fundamentals of pressure distribution and soil compaction under tractor tires. Agr. Eng. 39: 276-281, 290.

Toogood, J.A. and R.R. Cairns. 1973. Solonetzic soils technology and management. Dept. of Extension, The University of Alberta, Edmonton, Alberta, Canada Bull. B-73-1 First Edition.

ORGANIC SOIL SUBSIDENCE

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INTRODUCTION

Organic soils develop under anaerobic conditions induced by a perennially high water table. When the soils are drained and brought under cultivation they subside, that is, they settle and decrease in depth in response to physical forces and a dissipation of mass due to biological oxidation. Subsidence is rapid for the first five to ten years, after which the process slows down; but essentially it continues until most of the organic material is mineralized. The net effects of subsidence which are of importance to crop production are mainly an increasing difficulty in maintaining adequate drainage, and a deterioration of structure, leading to more difficult soil management and less than optimum productivity.

Subsidence is a natural and inevitable process which cannot be prevented in drained and cultivated organic soils. However, the subsidence processes can be slowed down considerably by using appropriate technology and management practices.

EXTENT OF THE PROBLEM IN B.C.

According to Soil Survey information, organic soils occupy about 1.86 million hectares or 6% of the land area in B. C. Most of this occurs in the northeast, and there are other large areas concentrated in the Lower Fraser Valley. Vancouver Island, coastal valleys, the Queen Charlottes, and in the Central Interior.

Drained and cultivated areas are largely limited to the Lower Fraser Valley and Vancouver Island, and here subsidence is recognized as a problem. The remaining organic soils are dominantly in interior wetland meadows where they are used for grazing. Very little is under cultivation, and only about 2000 to 3000 ha. are used for tame forage. The most important area of concern

is the South Coastal region. The Lower Fraser Valley has about 9240 ha. and Vancouver Island about 8920 ha. classified at Typic and Terric Fibrisols, Mesisols and Humisols. At most about one-third of this is drained and cultivated and undergoing subsidence. The soils in this area are recognized as a valuable resource, and they are used extensively for production of a wide range of high-value horticultural crops.

Long-time residents of the Glen Valley area tell us that the deeper organic soils, now mapped as Terric Humisols, have subsided as much as one meter in the past 50 or 60 years, or about 2 cm/year (Luttmerding, 1982). Farmers south of Cloverdale estimate subsidence of Terric Humisols and Mesisols to be about 45 cm in 20 years, or 2.25 cm/year. Subsidence is conspicuous in the area when observing the surface levels of cultivated fields compared with adjacent undrained areas or pastures.

Subsidence rates vary considerably, and have been shown elsewhere to range from 1 cm to 7 cm/year, with an average of 2 to 3 cm/year for soils at this latitude.

Degradation Effects of Subsidence

The degradation effects of subsidence are here seen to be (1) a gradual decrease in depth of soil above existing drainage tiles, rendering the drainage system less effective over time, and (2) a secondary effect of deterioration of soil structure due to humification of fibrous materials combined with excessive tillage and compaction by field traffic. Structural degradation in turn appears to aggravate the already poor drainage conditions, and leads to ponding and perched water tables during periods of heavy rainfall, even in the summer. Another factor which confuses our understanding of subsidence in these soils is the presence of slowly permeable strata resembling sedimentary peat. These strata occur at various depths, as shallow as 10 cm and as deep as 50 to 100 cm or more below the present surface.

These problems are generally recognized by farmers and agrologists, and they have been addressed usually on an ad hoc basis over the years. However, there have been no concerted efforts to study rates of subsidence or to develop practical and economic methods of controlling rates of subsidence for the affected soils in B. C.

CAUSES OF SUBSIDENCE

The processes contributing to subsidence have been studied in great detail and for many years. Studies have been made in the Netherlands (Schothorst, 1976); in the Holland Marsh in Ontario (Irwin, 1976); in Quebec (Jasmin, et at, 1981); and recently summarized with a Canadian perspective (Mathur, 1981, 1982).

There is general agreement among researchers as to the principal causes of subsidence, but there remains some uncertainty about the mechanisms involved and the best approach to controlling subsidence. The causes of subsidence have been identified as follows:

Settlement and Consolidation

After removing free water by drainage, the buoyant force of water is removed, and for each cm drop in the water table, the overlying material loses the upward buoyant force of 1 g/cm^2. The overlying materials then effectively become heavier, by about 200%, and subsequent consolidation accounts for about 30% of initial subsidence (Irwin,1976). Further settlement is caused by direct compaction from field traffic. Some, but not all of this, may be overcome by tillage. There is also a tendency for organic soils to become more compact in direct proportion to the intensity of tillage.

Shrinkage and Capillary Contraction

After lowering the water table by drainage, organic materials undergo dessication due to removal of gravitational water and increased evapotranspiration. This produces much higher surface tensions in the soil-water matrix and this results in shrinkage. This process is similar to the shrinkage of clays. The amounts of shrinkage have been found to vary from 12% to 87% loss in volume. Initially it is a rapid process which dimishes over time. Shrinkage probably accounts for one third to one half of the initial subsidence which occurs in the first few years after drainage.

Factors which affect the rate and amount of shrinkage include the degree of drainage and the density of crop roots and canopy, since these, in turn, influence the soil water content. It is believed that shrinkage continues,

although at a decreasing rate, until the organic materials are well-humified.

Shrinkage and consolidation account for 50% to 75% of initial subsidence. After this, subsidence continues chiefly as a result of biological oxidation and, to a lesser but significant degree due to wind and water erosion. In some cases fire and the removal of buried woody debris may account for substantial losses.

Biological Oxidation: Mineralization or Humification

This process accounts for about 20% of total subsidence, and for most of the subsidence which occurs after initial settling and shrinkage have taken place. Biological oxidation has been found to be limited almost exclusively to the top 20 cm in cultivated soils. Under the influence of drainage, tillage, liming and fertilizer use, organic materials undergo relatively rapid oxidation. Over the long term, for example, peat with an initial bulk density of 0.1 g/cm^3 is oxidized becomes more dense, with a bulk density of 0.4 g/cm^3. This corresponds to a volume decrease of 75%.

Mathur and others have concluded that as much as 60% of biological oxidation is brought about by free enzymes released during mineralization of organic matter, and that effects of enzymatic degradation can be significantly inhibited by additions of copper to the soil (Mathur, 1982).

FACTORS AFFECTING THE RATE OF SUBSIDENCE

It is important to recognize that there is great difficulty in accurately measuring subsidence rates and in predicting the exact effects of the many interrelated contributing factors. However, a number of these are fairly well understood.

Type of Organic Material

The rate and ultimate amount of degradation of organic materials is a function of the ease with which they can be oxidized. This varies with the type of carbohydrate compounds characteristic of the species of plant remains which constitute the soil material.

Water Table Level: Soil Air to Water Ratios

The most important factor influencing the rate of oxidation is the amount of oxygen in the soil as determined by drainage factors and cultural practices which influence soil water content and oxygen status. In one case, a water table held at 70 cm produced subsidence of 0.8 cm/year; at 120 cm it lost 1.6 cm/year; and at 170 cm, lost 3.6 cm/year (Mathur, 1981). A large root mass tends to deplete soil oxygen and thus slows down oxidation. Subsidence in pastures and under forage crops is about 50% of that in cultivated soils. The implications of cropping practices are obvious.

pH

Oxidation proceeds more slowly at low pH. Mathur (1982) reports that in one study 50% of the increased rate of oxidation as a function of increasing pH occurs between pH 4.0 and 6.0. On the other hand, liming to raise pH to higher levels more suitable for crop production has the effect of dissolving phenols, which behave as anti-oxidants. The removal of phenols by liming is seen to be a significant contributor to oxidation and subsidence.

Climate

Good correlation has been found between the logarithm of the rate of subsidence and the Lang Factor (mm annual precipitation divided by mean annual temperature ^{o}C). Climatic regimes accounted for five-fold differences in subsidence rates in one study (Mathur, 1982). Under B. C. conditions of relatively high total precipitation and summer irrigation, together with moderate summer temeratures, it is likely that coastal organic soils will subside more slowly than in warmer, drier climates.

Soil temperatures are also important in that the rate of oxidation as measured by the evolution of CO_2 is doubled for each 10°C increase in temperature. Such factors as crop density, soil water content, and tillage practices will influence soil temperature, and thus affect subsidence rates.

Initial Thickness

Here, too, it is well known that the thicker the organic material, the faster the rate of subsidence and the greater net subsidence will be. This is most important in that drainage systems must be designed to account not only for the expected total subsidence, but also for differential subsidence in certain parts of fields if organic materials are thicker.

Time

As organic materials become more humified, they oxidize more slowly, and it 's clear that the rate of subsidence decreases over time in cultivated soils.

EFFECTS OF SUBSIDENCE

Loss of Freeboard

Subsidence reduces the absolute elevation of the soil surface and therefore makes the design and operation of underdrainage systems difficult. It was found in Holland Marsh that as the soil subsided, the original drainage systems lost effectiveness and new systems had to be installed. This produced the startling result of rapidly increasing the rate of subsidence. Irwin (1976) determined that each subsequent attempt to drain the marsh would reduce its expected life by 30 years. Some Fraser Valley farmers are now experiencing failure of their drainage systems after 20 years, and they respond to this by installing more underdrains. In some problem areas, drains are being placed at spacings as close as 6m, yet with little effect on ponding. The inability to effectively drain these soils is becoming more and more serious, since efficient production of high value cash crops is adversely affected.

Increasing Compaction and Structural Degradation

Subsidence produces soils with increased bulk density, reduced porosity, and reduced hydraulic conductivity. These further aggravate poor drainage conditions. Under intensive tillage, soil tilth deteriorates over time and

in response to this growers overwork their soils, especially with rototillers. This in turn only hastens the degradation process.

Exposure of Underlying Acidic Organic and Mineral Layers

As subsidence proceeds and the depth of tiliage increases, there is a continual mixing of more acidic subsoil materials. This lowers soil pH in the plow layer and adds to the lime requirement. In the more shallow soils, the underlying mineral soils eventually come closer to the surface and become mixed with the organic plow layer. It has been shown that such mixing accelerates oxidation, although the mechanisms involved have not been fully explained.

Eventually, fields begin to show noticeable changes in the areal distribution of soil materials with radically differing composition, texture, structure and subsequent effects on crop production. In the Fraser Valley it appears to present slight, but manageable problems on some soils, but not on others, depending on the nature of the subsoil and the crops grown. Specific problems attributed to this condition include differences in soil temperatures which affect germination and maturity, but with minor difference in yields for most crops.

REMEDIES AND CONTROL MEASURES

Water Table Control

Subsidence is best and most effectively controlled by maintaining the water table at the highest level possible which is consistent with specific agronomic requirements of crops, and field trafficability. This means that water table control measures require much more precision than current farm practice and regional drainage capabilities will allow. Ideally, water tables should be constantly adjusted to the highest level which will allow the best crop growth, and at times when trafficking the field with machinery is necessary, the water table should be lowered to the point where compaction and structural damage are minimal.

In the Fraser Valley, most organic soils are deliberately allowed to flood, because drainage systems are barely capable of handling the large volumes

of water produced by the local climate, and because flooding is an effective means of inhibiting subsidence. In addition, flooding effectively decomposes bulky crop residues and culls, which interfere with seedbed preparation, and which will make volunteer growth in the subsequent crop.

This flooding also damages soil structure by dispersing colloidal soil particles, infilling of larger voids in the soil and subsoil, and especially noticeable is the effect of colloidal matter settling on the soil surface and creating a thin, very slowly permeable layer which impedes drainage and promotes ponding. The cumulative effects of flooding create a number of real problems for the grower, but these could be overcome in large measure through more effective water table control and soil management.

Cultural Practices

Reduced tillage

Excessive tillage is implicated in hastening subsidence, as well as damaging soil structure and aggravating drainage. Tillage should be reduced to the minimum consistent with optimum crop production. In Quebec, some growers have successfully grown most crops in a variety of peat soils with minimum or no tillage. They find that only tap-rooted crops such as carrots and parsnips require tillage.

Cover crops and crop rotation

Theoretically, the presence of a cover crop should inhibit subsidence by reducing evapotranspiration and depleting soil oxygen. M. Levesque (1981) suggests that when green manure is plowed under, the fresh supply of readily decomposible organic matter stimulates a flush of microbial activity which further decomposes the more resistant organic matter. Jasmin, et al (1981) are convinced that the cumulative benefits of cover crops offset this disadvantage. Cover crops are used, but not extensively, in the Fraser Valley.

It is recognized that most organic soils do not need crop rotation in the usual sense. The same crop can be grown on the same soil until disease sets in and makes rotation necessary. However, in light of the subsidence-inhibiting effect of vegetative cover and roots, it is evident that organic

soils should not as rule lie fallow any more than is practically necessary. The adverse effects of winter flooding would be reduced if a cereal crop with a well-developed root system were in place.

Applications of Copper

Over the past ten years, Mathur and others have determined that subsidence in cultivated organic soils can be decreased by 50 to 60% by moderately heavy applications of Cu as copper sulfate at rates which achieve and maintain Cu concentrations of 100 ppm in soils with a bulk density of 0.1 g/cm^3, or proportionally higher concentrations for soils with higher bulk densities. (Mathur 1981). Current recommendations in Ontario are based on this work, and we have adopted similar recommendations for B. C. The recommendation is to apply 15kg Cu/ha for each of the first three years of cultivation, and 5 kg Cu/na every second year thereafter, depending upon crop copper requirements.

Studies have shown that copper may be safely applied up to amounts equivalent to 5% of the soil C.E.C. without interfering with any other aspects of the soil environment. Furthermore, the copper effect has been shown to persist.

RECOMMENDATIONS

1. The efficient and productive life of B. C. organic soils should be preserved as long as possible. This should be ensured through research and extension efforts to determine and promote cost-effective management practices which will inhibit subsidence.
2. A program of monitoring subsidence should be initiated in the more economically important areas, such as the Lower Fraser Valley and Vancouver Island.
3. Emphasis should be placed on continual improvement of water control systems design and installation on farms and within drainage districts, to facilitate more precise control over water table levels and thereby inhibit subsidence.
4. Extension programs should be augmented to promote practical means of preserving organic soils.

References

Irwin, R.W. 1976. Soil Subsidence of the Holland Marsh. Eng. Tech. Pub. 126-34. School of Engineering, University of Guelph, Ontario.

Jasmin, J. J., Hamilton, H.A., Millette, J., Hogue, E. J., Bernier, R., and Campbell, J. A. 1981. Organic Soil Reclaimation. Technical Bulletin 11. Research Branch, Agriculture Canada, Ottawa, Ontario.

Luttmerding, H. 1982. Personal Communication.

Levesque, M. 1981. Personal communication.

Mathur, S.P. 1981. "The Inhibitory Role of Copper in the Enzymatic Degradation of Organic Soils. L.R.R.I. Contribution No. 150." Proc. Int. Peat Symposium, Bemidji, Minnesota, Oct. 21 - 23, 1981.

1982. "Organic Soil Subsidence: A Scan of Conventional Wisdom and Current Research." Review Article, L.R.R.I., Research Branch, Agriculture Canada, Ottawa, Ontario.

Schothorst, C.J. 1976. "Subsidence of Low Moor Peat Soils in the Western Netherlands." Geoderma, 17 (1977) 265-291, Elsevier Scientific Publishing Company, Amsterdam.

Slavinski, H.C. 1978. "Organic Soils in British Columbia." Mimeo of brief submitted to E.L.U.C. Secretariat, Victoria, B. C.

"DEGRADATION" EFFECTS OF IMPROPER WATER MANAGEMENT

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1. Introduction

Water has an effect on the productivity of the soil. Whether that effect is positive or negative depends on the circumstances under which water occurs in association with the soil. If the soil receives more water than can be utilized by vegetation or discharged from the soil, saturation occurs and in most cases leads to reduced productivity of the land. There are, however, many exceptions. In time, saturation produces bogs and marshes with a potential for productivity greater than the original soil. While the agricultural productivity of a marsh may be low or absent at a certain time, it has nevertheless future capability of becoming productive and indeed be in the process of raising its future productivity capacity by remaining flooded or saturated. We would, therefore, consider a bog as being in the process both of degradation as well as ascending in productivity potential depending on the criteria used or the point of view that is taken. The term degradation is, therefore, not without its problems in dealing with certain soil and water conditions and processes and may indeed not be a particularly suitable one. From the foregoing, it is evident that, while it is possible to make a judgment as to the condition of a soil-water at a particular time, it is a lot more difficult, if not impossible, to do so in regard to the nature and magnitude of debilitating processes that are going on, if any. In other words, short term enhancement may be long term degradation. Quotation marks have been added to the title to focus attention on the sometimes ambiguous or inappropriate character of the term degradation in much of what can be said about soil and water management in B.C.

2. Nature and Extent of Wetlands in B.C.

Wetlands are those lands which are saturated or flooded with water long enough to promote aquatic processes as indicated by hydrophylic

vegetation, gleying and peat formation or lands which are covered with water up to 2m deep.

A significant part of B.C. is covered by wetlands and efforts are still underway to determine the extent in an accurate and meaningful manner. However, a map (Fig. 1) prepared by Environment Canada in 1981 provides an overview of the occurrence of wetlands in British Columbia and the following table gives a breakdown of percentage of area of wetlands for each agricultural reporting area.

DISTRIBUTION OF WETLANDS
BY AGRICULTURAL REPORTING AREAS

A.R.R.	Area of C.L.I. 1-7 Classified Land (Ac)	Estimated % Wetland	Area of Wetland (Acres)
Cariboo	10,195,801	10%	1,019,580
Island	1,138,661	4%	45,546
Kootenay	16,986,980	3.5%	594,544
Mainland	2,367,957	12%	284,155
Okanagan	6,549,271	1.5%	98,239
Omineca	8,512,123	7%	425,606
Peace	11,775,189	20%	2,355,038
Skeena	7,160,864	3%	214,826
Thompson	9,432,379	4%	377,295
TOTALS	74,119,225	7.3%	5,414,829

3. Improper Water Management

Improper water management in the context of this paper is regarded to constitute that management which causes the land and the soil to be

DISTRIBUTION OF WETLANDS
IN BRITISH COLUMBIA

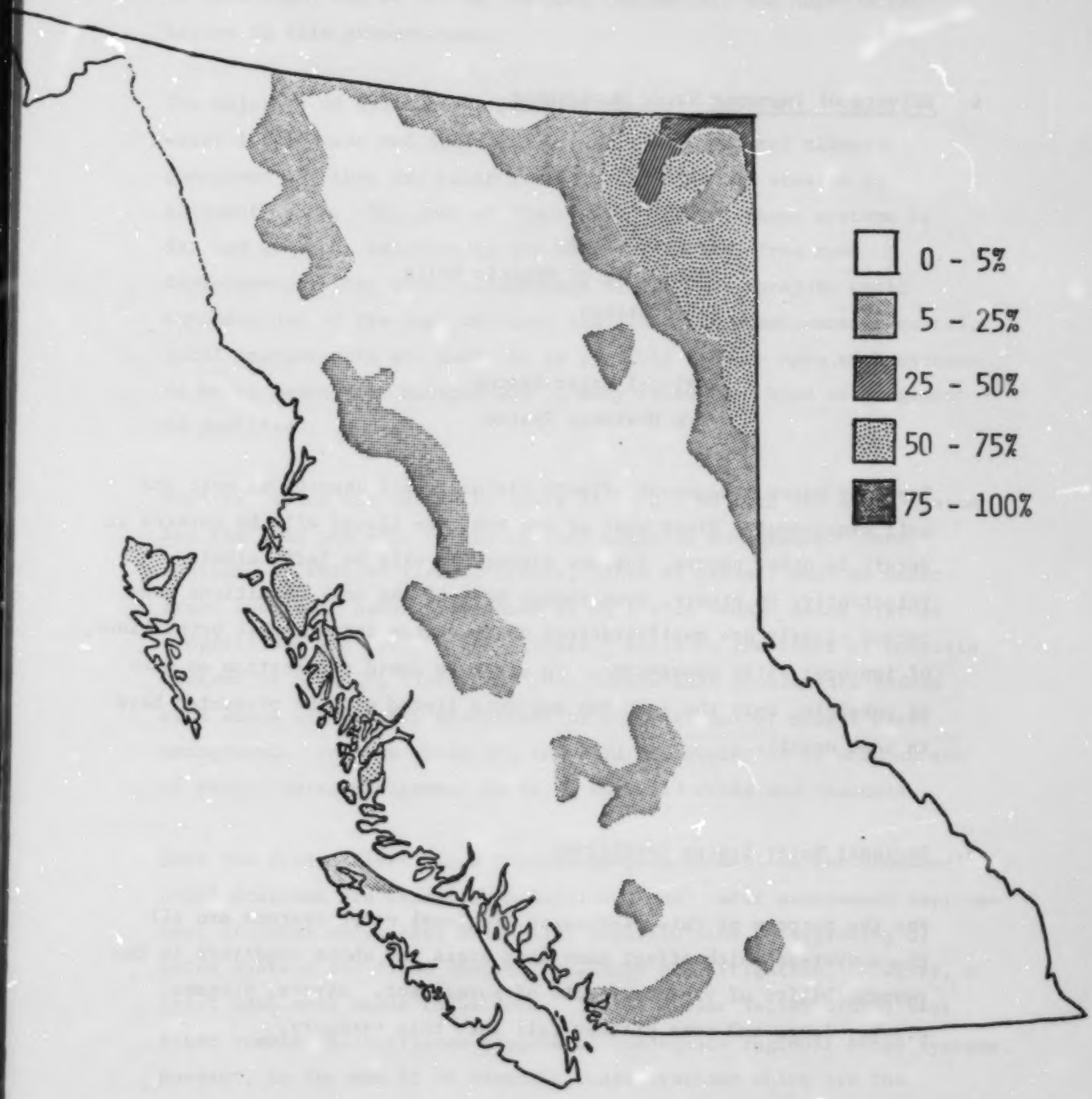

Figure 1.

affected adversely in the present and the immediate future for common agricultural pursuits under currently accepted economic concepts.

4. Effects of Improper Water Management

Erosion
Compaction
Nutrient Loss
Subsidence of Organic Soils
Salinization

Regional Water System
Farm Drainage System

Improper water management affects virtually all aspects of soil and soil management. Since most of the subjects listed will be covered in detail in other papers, further discussion will be left, albeit reluctantly, to others, even though many of the soil conditions concerned clearly are manifestations of sometimes catastrophic proportions, of improper water management. In order to avoid duplication as much as possible, only the last two subjects listed will be presented here in some detail.

5. Regional Water System Conditions

For the purpose of this discussion, regional water systems are all those systems which affect many land users and whose condition is the responsibility of various levels of government. Rivers, streams, creeks, lakes and some ditches fall into this category.

The vastness of the province of British Columbia and the diversity of water systems with a regional character is of such overwhelming proportion that any attempt of categorization, let alone assessment of condition, can be but of the most rudimentary and superficial nature in this presentation.

The majority of systems are in their natural condition. Their water levels rise and fall in accordance with natural climatic phenomena and they may cause periodic flooding and erosion on adjacent lands. The cost of "improving" many of these systems is far too great in relation to the benefits derived from such improvements, that such improvements usually are foregone until expanded use of the land warrants the financial commitments required. Until improvements are made, it is possible to look upon such systems as being improperly managed and in many cases that kind of judgement is justified.

However, there are instances where it is not so much the water system but the land use adjacent to it that requires management. Water systems, be that of rivers, creeks, lakes or oceans, must be understood and their nature respected if we are to manage water systems properly and wisely. To thoughtlessly build on the banks of mountain streams or braiding rivers and then demand that governments defend such works with costly structures is not rational or proper water management. To know where not to build or develop is as much an act of proper water management as it is to build dykes and channels.

Both the Fraser River Flood Control program as well as the ARDA and ARDSA programs are examples of major regional water management improvement programs which have made major contributions to upgrading of water systems for flood control, drainage and irrigation. However, a great deal more needs to be done. In the Fraser Valley alone, vast areas remain underutilized because of inadequate regional water systems. However, in the end it is economic considerations which are the determining factors as to whether and where improvements are made and

as long as financial resources are scarce only the most urgent and the most economically rewarding projects are undertaken. This means that regional water systems will never be fully adequate everywhere at all times.

6. Farm Drainage Systems

The combination of high water additions to the land through climatic phenomena and irrigation practices and restricted hydrological soil systems leads to unfavourable land use conditions. Alleviation of excess water is being achieved by collecting and channeling the excess water away using open surface channels as well as buried perforated conduits. Records of construction of open channels are not being kept and attempting to estimate the extent of construction of open channels on farms in all of British Columbia would be an exercise in futility. Suffice it to say that open channel construction is going on continually by the most diverse means imaginable and with the greatest diversity of quality throughout the province of British Columbia at all times. That some of these channels fail to function almost at the instant of construction is a matter of record. Some function a good deal longer than others but all suffer immediate onset of decline which proceeds at greatly varying rates. The diligence and skill with which maintenance is undertaken also is subject to the same variables as those of construction and since surveys of farm channel conditions are normally not conducted, we are left to speculate that the condition of open farm channels is somewhere between excellent to very poor with the majority being somewhere in between.

Underdrainage using porous or perforated conduit buried into the ground is now being used instead, and in conjunction, with open channels as a means of controlling excess water in the soil. Records of underdrainage is rather more extensive than that of open channel construction as the majority of such drains are constructed by a small number of contractors with specialized equipment. However, early methods dating back more

than 100 years consisted of hand construction using cedar boards in various ways to form channels or conduits. Records of these early drains are sketchy but they are scattered around the Fraser Valley and a few locations on Vancouver Island, and doubtless elsewhere. While some of these drains continue to function today, most of them have gradually disintegrated or silted up.

Underdrainage came not really into its own until Hans Hoffmann, a Machine Shop Operator in Pitt Meadows, built a wheel trencher similar in design to the Buckeye Wheel Trencher in about the mid 1940's. From that time on, drain construction steadily increased to where in 1982 total volume amounted to 1,584,400 ft. installed by four drainage contractors using three high-speed chain trenchers and one drain plow equipped with laser grade control. Cedar drains gradually gave way to more and more clay tiles and in 1970 corrugated perforated plastic drain tubing was introduced, quickly replacing the cumbersome, heavy baked clay tile probably forever (Fig. 2).

Most, if not all, underdrains undergo decline in effectiveness over time. This is particularly true for early plank drains which have largely collapsed or silted up even though a few are still surprisingly effective. Many early drains also suffered damage and reduced effectiveness or total failure due to shallow installation. Particularly drains in organic soils are being plowed up both due to shallow installation as well as due to decomposition and subsidence of peat. Other causes of drain decline are listed below in approximate order of importance.

CAUSES OF DRAIN DECLINE

1. Deteriorated Soil Structure
2. Clogging with Ochre
3. Outlet Condition
4. Drain Outfall

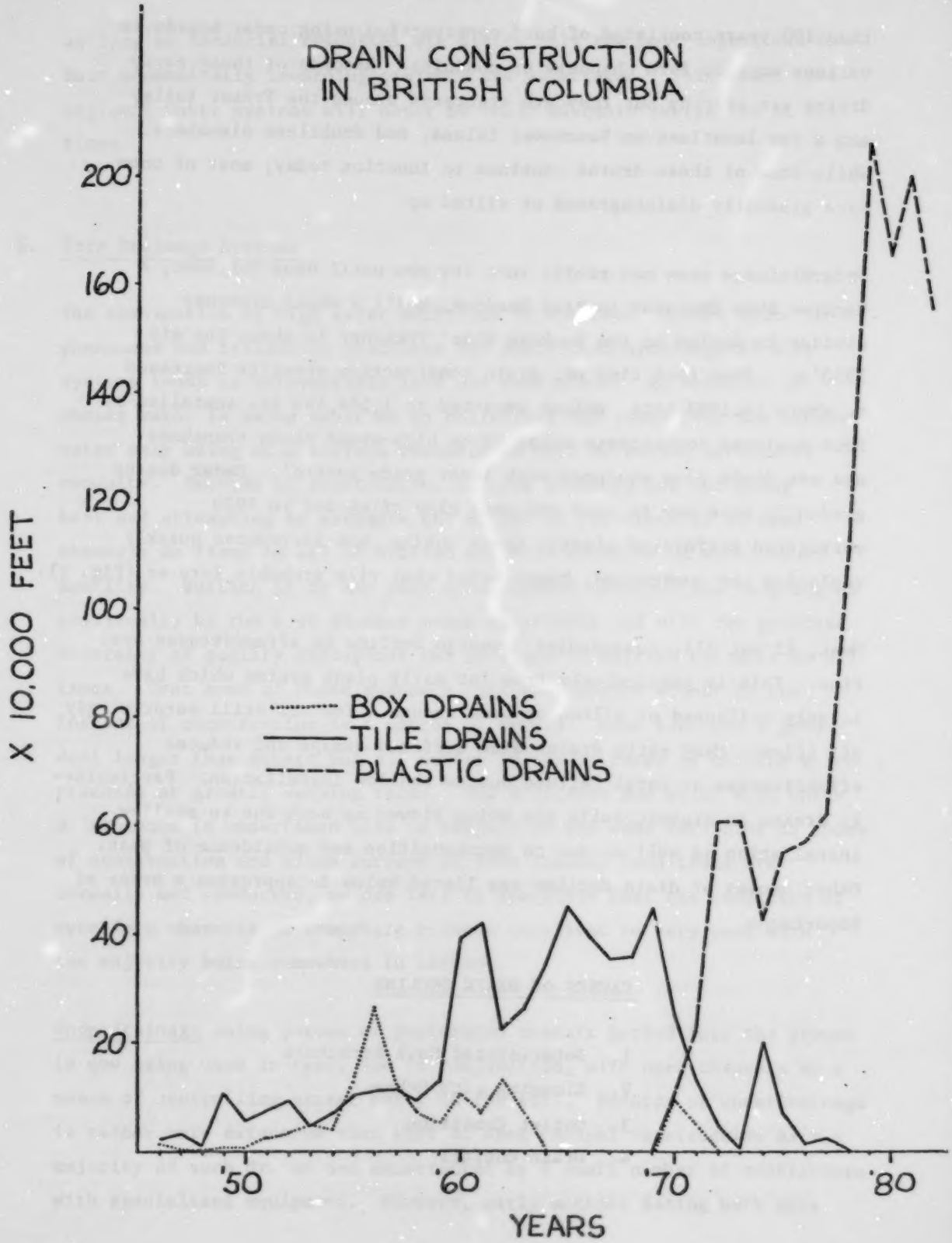
DRAIN CONSTRUCTION
IN BRITISH COLUMBIA
X 10,000 FEET
200
160
140
120
100
80
60
40
20
BOX DRAINS
TILE DRAINS
PLASTIC DRAINS
'50
'60
'70
'80
YEARS

Figure 2.

5. Clogging of Drain Filter
6. Piping Due to Fine Sand
7. Shallow Installation
8. Subsidence of Organic Soil
9. Breakage or Deformation
10. Sealing of Joints (Clay Tile)
11. Misalignment of Tiles (Clay Tile)
12. Erosion
13. Rodents
14. Improper Construction
15. Poor Design

The extent of decline of drainage systems is open to wide speculation. Without extensive checking, estimates are strongly subject to error but in the absence of data an attempt is made here to express drainage decline quantitively on the basis of observations over many years.

Degree of Impediment	Proportion of Drainage Systems
Few or No Impediments	40%
Minor Impediments	30%
Moderately Severe Impediments	20%
Severe Impediments - Total Failure	10%

It would appear that the most common cause of drain decline is deteriorated soil structure due to soil management practices and general land use which is covered by other papers of this conference.

Clogging of drains with ochre is also a frustrating and baffling phenomenon in drainage and possibly one of the most crippling. There is no effective known remedy for ochre which consists of gelatinous iron algae and iron compounds and can render a drainage system inoperative in a few years.

Outlet conditions i.e. the water level in the outlet ditch often is too high to permit free gravity flow of the drain resulting in poor performance of the drainage system. This problem is widespread and may even be more extensive than the occurrence of ochre but remedial measures are a great deal easier. Closely associated with the outlet structure is the outfall of the drain; the point where the drain discharges into the outlet ditch. Very few drains have proper provisions for protection at this point and, consequently, many drain outfalls are damaged from ditch clearing machines and also from ditch bank failure. Clogging of drain filters, particularly of the synthetic "filter sock" type now much in use, is causing some concern, although no reliable information is available of the extent of this problem. Much of the cause of filter clogging is inappropriate application of the "sock". Piping, the inflow of fine sand into a drain, still occurs occasionally but the problem has been very much reduced with the introduction of continuous tubing, and effective filter materials. Shallow installations, rather common in the early days are rarely the cause of drain failure today, but a few farmers that do their own installation sometimes make this mistake still. This is particularly damaging in organic soils which subside due to decomposition and settling.

Breakage of drains, once a minor problem, has been eliminated with plastic drains. Instead, there is the problem of potential deformation largely due to improper construction methods, but partially due to drain quality. Few trencher installed drains suffer from deformation problems since generally good "bedding" is provided which holds the drain in place. This is not the case with back-hoe installations. Backfilling with this method does not insure uniform bedding of granular material around the drain allowing for deflection to the side. Sealing of tile joints or misalignment of tiles is no longer a problem. Erosion, rodents, improper construction and poor design all are responsible at one time or another for poor drainage performance but generally rank substantially lower in importance.

7. Remedial Measures

Enough could be said about remedial measures of poor drain performance to warrant a separate paper. However, most of the measures are concerned either with the condition of the soil or the maintenance status of the entire drainage system. Since the subject of soil compaction and remedial measures is treated elsewhere, it will not be repeated here. That leaves the matter of maintenance. Maintenance is the greatest factor in poor drainage performance after soil compaction. Standards of both regional as well as private drainage and water conveyance systems are, with obvious exceptions, not particulary high. Regular maintenance readily can overcome much of this cause of soil degradation which is largely a matter of need, awareness and costs. But some of the problems of under-drain condition is the lack of special maintenance equipment. Nowhere in British Columbia, for instance, is there a single drain cleaner present, let alone contractors that specialize in cleaning or maintaining drains. Piping, sedimentation and ochre will remain to be a problem until proper drain cleaning capabilities are developed in British Columbia.

SOIL CONSERVATION AND LINEAR DEVELOPMENT IN BRITISH COLUMBIA (TRANSMISSION AND PIPELINES)

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B.C. Hydro

INTRODUCTION

Linear rights-of-way constitute a significant surface disturbance in British Columbia. At present, main electric transmission lines [illegible] kV) and pipelines (gathering and transmission) traverse approximately 7,500 and 5,300 kilometres of the province respectively. This represents an area in excess of 45,000 hectares that has undergone some degree of surface modification. Approximately 70% of this is forest, mixed vegetation and grassland, and 30% is within the Agricultural Land Reserve (largely uncultivated). New projects in various stages of planning could require an additional 35,000 hectares of right-of-way. Fortunately electrical transmission and pipelines do not exclude all other uses as roads do and valuable production for agriculture and wildlife is still possible.

POTENTIAL EFFECTS ON SOIL

Soil Erosion and Mass Movement

Accelerated soil erosion resulting from physical disturbance and removal of vegetation reduces land productivity, can hamper revegetation efforts and result in discharges of unwanted sediment to lakes or streams. Although the mechanisms of soil erosion are well understood, quantitative predictive tools are of limited application in British Columbia terrain. Primary soil characteristics which have been shown to have a direct relationship to erosion

are: texture, structure, stoniness, depth of surface horizons, infiltration capacity and permeability. Additional site characteristics that can help to predict soil erosion include: slope (steepness and length), vegetation and litter cover, climate, and microtopography.

Swamps, streambanks and steep slopes are particularly sensitive to accelerated erosion. It is also known that under permafrost conditions removal of the insulative organic layer can cause segregated ice to melt and create saturated soils that erode easily and are difficult to revegetate.

Cut slopes and drainage modifications particularly those resulting from road construction and pipeline trench excavation may increase mass movement. Such sliding or slumping is often induced by altering the subsurface flow of water. Mass movement is greatest on steep slopes, fine-textured soils and bedding planes oriented parallel to the slope.

Soil Displacement, Mixing, Compaction and Infiltration Loss

Soil displacement involves mixing soil horizons or movement from one point to another. This can occur when soil is pushed around a site, trenches are excavated or to a lesser degree as a result of vehicle rutting. Mixing leaves soil unevenly distributed and can increase rates of surface erosion. The texture of the surface layer may be altered, its organic and nitrogen content lowered and undesirable salts mixed into it.

Soil compaction can reduce infiltration, air and water holding capacity and increase surface runoff or ponding. Wet soils lacking in organic matter such as river silts are particularly susceptible to compaction and plant growth can be restricted for several years.

Nutrient Loss, Increased Soil Temperature and Soil Contamination

Removal of vegetative cover on the soil surface may lead to loss of soil nutrients. Burning of slash can lead to volatilization and leaching of nutrients.

Increases in soil temperature can occur when vegetation is removed and the soil surface is exposed to solar radiation, particularly on south facing

slopes. Elevated soil temperatures hasten drying of the upper profile making revegetation more difficult and exposing the soil to possible wind erosion.

Occasional spills of petroleum products or construction materials can contaminant the soil. Improper use of persistent herbicides for vegetation control may leave residues in the soil that influence its productivity.

ASSESSMENT OF EFFECTS

The degree of soil loss due to right-of-way construction depends primarily on terrain sensitivity, climatic conditions, and the construction and reclamation techniques employed. Because of their complex land forms, soil patterns and hydrological regimes, mountainous forest lands are particularly susceptible to increased soil erosion from linear development. With careful access planning and construction monitoring, losses can be kept to a minimum. Arid plateaus are susceptible to wind erosion but usually are subject to less surface disturbance than mountainous regions.

Mixing soil horizons and compaction are the most significant changes that can directly affect agricultural production. However, both of these affects are also associated with agricultural development and cropping and the added effects attributable to right-of-way development are generally minor. Additional compaction or mixing is primarily a matter of economic concern on individual properties.

Significant problems with soil mixing and compaction are not widespread in British Columbia. Although severe compaction is difficult to fully eliminate through normal agronomic practices, its effects can be reduced significantly by deep tillage. Most concern associated with soil mixing and right-of-way development involves pipeline trench excavation and much of this can be relieved where necessary by stripping and replacing top soil. Increased soil erosion due to linear developments is not as common on cultivated agricultural land as in mountainous terrain because slopes are less severe. Land clearing often benefits agriculture since it is required prior to cultivation or range improvement.

MITIGATION MEASURES

A number of measures may be used to conserve soil on transmission and pipeline rights-of-way.

Route Selection

Multi-disciplinary studies can be conducted as part of route selection. Where possible sensitive terrain can be avoided. Cultivated agricultural lands should be carefully identified so that special tower placement can be considered if necessary. Multiple use of corridors can reduce the area of surface disturbance.

Access Planning

A thorough review of available environmental reports should be done prior to access planning. Careful planning and flagging of road locations can reduce the length of new road construction and ground disturbance.

Land Clearing

Hand clearing is often used on slopes that are sensitive to erosion (generally over 35%) and tree stumps are not removed. This applies mainly to construction of transmission lines. Where ground conditions are very difficult, road access may not be possible and tower installation is done by helicopters. Ravines and streams can often be spanned with minimal clearing. Sensitive areas may be cleared when soils are dry or frozen to minimize impacts from thawing, compaction or soil mixing. Use of brush blades on bulldozers can minimize soil disturbance and incorporation of soil into brush piles. In some situations rubber-tired equipment will reduce surface disturbance, compaction and mixing.

Under some wet soil conditions trees are hand felled a year before stump removal. This allows drying of the soil from sun and wind and reduces soil accumulation in the brush piles when clearing is completed.

Soil Erosion and Mass Movement

Cut and fill slopes can be minimized and surfaces rounded prior to revegetation. Water bars, ditch blocks, culverts and drop structures can be utilized to protect access roads and the right-of-way from erosion. Winter construction will also minimize ground disturbance where wet soil or permafrost occurs and thereby reduce erosion.

Top Soil

Under special circumstances the surface layers may be stripped and stock piled prior to trench excavation. This generally applies to high capability agricultural soils with a significant organic layer and subsoil texture or salt concentrations that would be detrimental if brought to the surface. Soil is later back-filled in the reverse order to excavation.

Compaction

Compaction can be reduced by avoiding operations during periods when the soil is wet. Winter construction also minimizes compaction and rutting. Avoiding unnecessary use of heavy equipment and restricting construction traffic to the right-of-way will also reduce the extent of compaction. Deep tillage will relieve compaction of the upper layer.

Soil Contamination

Stringent controls on handling and storage of possible contaminants, pipeline emergency shutdown systems and careful selection and use of herbicides for vegetation management can greatly reduce the risks of soil contamination.

Construction Monitoring

Regular inspections to ensure construction activities meet environmental guidelines and specifications can reduce soil losses at specific points.

Toward the end of the project cleanup, reclamation and revegetation should also be done to ensure soil stability. Effective revegetation is one of the best means of preventing long term erosion problems.

SLIDES

The following slides illustrate various phases of linear development. They provide a visual indication of the extent of soil disturbance which occurs and some of the measures employed to reduce detrimental effects.

PIPELINE PROJECTS

SLIDE NO.	PROJECT PHASE	DESCRIPTION
1	Rough Grading	Note multiple use of corridor (pipeline parallels Hydro).
2	Ditching	Drilling and blasting ditch work.
3	Ditching	Winter use of ditching wheelworks only in muskeg or agricultural area where rocks are not encountered.
4	Ditching	Open ditch "wet" technique of installing buried pipelines across a river.
5	Pipe stringing, bending & welding	Winter conditions, berm of snow and slash insulates ground from frost penetration facilitating ditching.
6	Lowering and back filling	Back filling follows closely so ditch is not left open for long periods.
7	Clean-up and recontouring	Level terrain.
8	Clean-up and recontouring	Sloped terrain.
9	Seeding	Aerial seeding on snow (moisture source) in late winter.
10	Revegetation	Results one season following construction, note surface breakers to control erosion.
11	Revegetation	Northeast Muskeg one year following construction, shows natural cover that remains following winter construction.
12	Revegetation	Six years after construction, Chetwynd area, ROW contains three lines.
13	Revegetation	Peace Region six years following, harvesting hay.

TRANSMISSION LINES

SLIDE NO.	PROJECT PHASE	DESCRIPTION
1	Clearing, Piling, Burning	Merchantable timber is harvested first, note brush blade which reduces soil accumulation in brush piles.
2	Cleared ROW	Debris removed.
3	Cleared ROW	Sensitive terrain, trees limbed and left flat on ground.
4	Tower Installation	Using crane.
5	Tower Installation	Using helicopter on hand cleared slopes.
6	Tower Installation	Using helicopter on hand cleared slopes.
7	Tower Installation	Showing base of tower specially adapted for rough terrain.
8	Line Stringing	
9	Attaching Line to Insulator	
10	Anchor Installation	Showing required surface disturbance.
11	Seeding	Helicopter - using J-Tac aerial hydroseeder.
12	Seeding	Helicopter - using J-Tac aerial hydroseeder.
13	Revegetation	Aerial inspection.
14	Revegetation	Steep slopes, water bars.
15	Revegetation	Checking trail plots using hand planted low growing shrubs, note some stumps left in the ground.
16	Revegetation	Planted shrubs.
17	Agricultural Use	Just planted soil under multiple corridor - Delta.
18	Agricultural Use	230 kV line over market garden - Richmond.
19	When all goes well	

DEGRADATION EFFECTS OF LAND CLEARING

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Introduction

Throughout man's history, forests have provided materials for shelter, fuel, tools, and recently, industrial products. The removal of forests has furnished man with a land base for settlement and the capacity to endeavor in a systematic production of food crops.

Until recently, forests were cleared by axe, handsaw and fire. The rate at which this clearing was achieved was variable. In heavily timbered areas, it was not unusual for only 1 - 5 hectares per farm per year to be cleared 40 - 60 years ago. Since the development of large land clearing machinery, 60 - 100 hectares can be cleared in a single season on one farm.

The rapid development from forest to farmland has raised some questions on how soils are affected for subsequent crop production.

A review of literature has indicated that very little effort has been spent on monitoring changes in soil qualities as forests became farms. Perhaps, it has been regarded that once soils underwent years of cultivation, the soil environmental conditions change dramatically as to make the transitional stage effects inconsequential.

In British Columbia, however, it appears that some effect on the initial crop years after clearing can be adversely affected by poor land clearing and breaking practises. While most soil research has examined the effects of forest removal on the soil qualities in future forest production, some of the results may be applied to the effects on agricultural crop production.

Agricultural Land Development Patterns in British Columbia

In 1901, there were 191,744 hectares of improved farmland and

73,606 hectares of crops (Statistics Canada 1951).+ Eighty years later, there has been a 394% increase in improved farmland area and a 672% increase in the area in crops. From 1971 to 1981, there has been an overall 33% provincial increase of improved agricultural land. The Central and Thompson regions have seen the most development in percentage terms, with a 90 and 75% increase respectively in the improved farmland classifications during the same 10 year period. The Lower Mainland has seen a 5% increase of improved farmland during this period (See Table 3).

An examination of the amount of land cleared with assistance from the Agricultural Land Development Act of 1946 can be seen in Tables 5 and 6.

Seventy five percent of the total land clearing assisted by A.L.D.A. has taken place in the Central and Peace River regions. Nearly 50% of the total amount has been cleared in the last 18 years in these two regions. It is probable to assume that land clearing patterns using private funds are similar and represent a majority of the land being developed in these regions.*

Soil Erosion from Land Clearing

Erosion is one of the most serious forms of soil degradation that occurs. This topic is examined in detail in other papers presented at this workshop, and so will only get a brief discussion here.

Recent land clearing and breaking activities, which resulted in erosion, have taken place on the glacio marine upland soils of the Central Fraser Valley. C. Wood (Personal Communication 1983) estimates that 1000 - 1200 hectares of this land has very high potential for soil

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+ Improved farmland is defined as the total of four agricultural land use categories by Statistics Canada: crop land, improved pasture, summer fallow and other improved land. Other improved land includes barnyards, gardens, farm roads and lanes, idle farmland and areas of unseeded new breaking. Area in crops is defined as areas planted or to be planted to crops in the census year.

* Central region staff of the B.C. Ministry of Agriculture and Food indicate that more clearing has taken place with private funding than with A.L.D.A. assistance.

erosion. The impermeable subsoils, rearranged medium textured surface soils, high precipitation and relatively steep slopes (10 - 18%) create a situation where erosion could be common place. Population pressures, market conditions and land values have spurred the development of these areas for valuable small fruit production.

Some recent work by the Soils Branch, B.C. Ministry of Agriculture and Food, is proving to alleviate erosion under arable cropping conditions.

Soil erosion is a problem in some areas of the province, most notably the Peace River region. However, there are few areas suffering from erosion directly caused by recent clearing and development.

Soil Compaction

Forest soil studies (Dickerson 1976 and Pritchett 1979) indicate that timber harvesting equipment can cause soil compaction resulting in reduced tree seedling growths. The compaction results from equipment operation during wet soil conditions and is most extensive on fine textured soils.

Recommendations minimizing compaction in forested areas entail concentrating traffic to a few major trails, avoid operating in wet weather and/or wet soil conditions; the mechanical shattering of soils with subsoilers is not an unusual practise to alleviate compaction effects (Pritchett 1979).

There is at the moment no substantial evidence that soil compaction resulting from land clearing operations is affecting crop production in British Columbia. However, the possibility exists that compaction damages could be occurring in the Central and Peace River regions where land clearing is the most active (Tables 3 - 5). The soils in these areas are predominantly fine textured and are usually wet in late fall or early spring. A major portion of land clearing in these areas takes place in winter on frozen ground, avoiding a considerable potential for creating compaction damages.

Poor land clearing practises could be cause of soil compaction. The movement of soil and humus into windrow piles bares the subsurface mineral soil. Subsequent operations that rework windrow piles may cause further compaction damage, especially if conducted under moist soil conditions. The interwindrow areas would be the most likely spot for compaction to occur.

Cultivation may either alleviate or increase compaction depending on the moisture conditions of the soil at the time of operation. Fine textured, low organic matter soils are especially prone to compaction damage as the optimum soil moisture range for cultivation is very narrow.

In their study of alfalfa growth on a newly cleared soil in the Central region of British Columbia, Lowe and Bomke 1982, indicated that the poor growth on the interwindrow soils may be due in part to compaction arising from the clearing operation. Increases in the ash and charcoal contents of the windrow soils, plus possible improvements in soil structure resulting from intense heat (Ralston and Hatchell 1971) may bias the comparison of bulk densities between these two soil zones. The windrow soil may in fact have had its bulk densities decreased in relation to the interwindrow soil due to these factors.

It is the feeling of this author that the Gray Luvisol (Gray Wooded) soils of the Central and Peace River regions of British Columbia are the most likely to have compaction damages inflicted on them.

Organic Matter Losses

The organic matter fraction of a soil is a source of nitrogen, phosphorus and sulphur for crop production (Allison 1973). It influences the moisture holding capacities and the structural stabilities of soils.

Soils with fine textures or inherently low organic matter levels are those most adversely affected by poor land clearing practises which scalp the organic matter and deposit it in the windrow piles.

Significant removals of organic matter on Gray Luvisol soils increase soil crusting and baking, weaken soil aggregate stabilities and decrease the levels of native fertility. These enhance the possibilities for initial crop failures. Examples of this condition can be encountered on the Gray Luvisols of the Central region of British Columbia.

Inexperienced operators are the major cause for this type of soil damage. Windrow piles burn poorly and usually need to be reworked, possibly resulting in compaction damages to the soil. The organic matter and topsoil loss can never be respread out over the area it came from. The extent of damage in British Columbia is not known, but the effects are lasting.

Initial Breaking Operations and Land Levelling

The initial cultivation of cleared land tries to:

- remove roots and small stumps with a minimum of operations
- incorporate organic matter through the rooting zone
- prepare the soil to seed bed condition quickly to provide a return to land development costs

To achieve these objectives, the cultivation is usually done with large moldboard or heavy disc plows.

Soils with shallow surface horizons and low organic matter levels are often cultivated too deeply. If the organic matter is buried, it may increase the degree of crusting. Potential crop productivity can be decreased when sufficient quantities of illuviated Bt horizons of Gray Luvisols are brought to the surface.

Levelling land can expose subsoils which are either infertile coarse textured or high in calcium. This is encountered most often on alluvial soils where old water channels and scars need to be filled in. Stockpiling of surface soils and filling depressions with subsoils are recommended.

The "Windrow Effect" on Crop Production

The most visible effect associated with land clearing is the improved crop production on windrow areas.

Legumes in particular show more vigour as well as higher productivity on windrows. Leguminous plants are often more prevalent in a burned forest area (Cooper 1971). Increased nitrogen fixation has occurred in the mineral portion of forest soils after burning (Jorgensen and Wells 1971, Wells 1971).

That improved legume growth may be due in part to the organic matter pushed into windrow piles (Lowe and Bomke 1982) has to be regarded as minimal due to a significant reduction occurring in the organic matter and total nitrogen contents of soils and above ground materials result from the intense burning of the windrow piles (Pritchett 1979).

Burning of forests has been shown to increase the <u>availability</u> of most nutrients (Mg, Ca, K, P) in forest soils (Feller 1982). Increased

pH, temperature and base status on burned soils appears to favour symbiotic and non-symbiotic nitrogen fixation (Jorgensen and Wells 1971, Wells 1971). Lowe and Bomke 1982, found that similar results with significantly higher Ca, Mg, Na and pH levels in a windrow soil than the interwindrow soil. Increased total nitrogen values in the windrow soil may have been caused by enhanced N fixation by either free living or symbiotic microorganisms (Lowe and Bomke 1982).

High manganese levels had been thought to decrease growth of forages between windrows (Mason, Dawley and van Adrichem 1976). Lowe and Bomke 1982, found that alfalfa on windrow soils had half as much foliar Mn as interwindrow samples. It was felt that dilution effects were more likely the cause of such differences as soil test levels were not significantly different for windrow and interwindrow soils.

Intensive heat from burning windrow piles may have some effect on soil structure. Ralston and Hatchell 1971 indicate that the "loss of structural water permanently alters the shrinking and swelling of montmorillonite clays to the extent that heat treated clay aggregates have soil moisture properties similar to sand or gravel". Increases of soil aeration after intense burning has also been noticed. Under certain circumstances, it may be possible for hot windrow fires to have an improving effect on heavy clay soil textures. This may also account in part for the improved growth of both legumes and grass forages on windrow sites.

The difference in crop growth between the windrow and interwindrow areas may not be due totally to soil degradation, but rather it may be an improvement of chemical and structural soil components of soils found under windrow piles.

An adverse effect on crop production and soil qualities has been noted by C. Wood (Personal Communication 1982). Wood reports that poor growth on strawberries and raspberries results in some Fraser Valley soils where circular burn piles of 9 - 12 meters in diameter existed previously. Adverse soil structure and fertility factors associated with large quantities of ashes are attributed to the poor growth of these crops. Large quantities of ashes could result in poor soil structure, possible ash cementation, high soluable salt contents and micronutrient toxicities (Allison 1973).

It is probable that due to the size of the trees cleared in the Lower Mainland that concentrations of ash detrimental to crop production are created.

Spreading of ashes after burning may avoid these adverse conditions. Ash cementations could be broken with subsoil cultivators.

Summary

Land clearing practises can have lasting detrimental effects for agricultural crop production. Poor land clearing techniques may increase the risk of initial crop failures and increase required nutrient inputs. The soils of British Columbia most susceptible to sulphur degradation are those with shallow profiles, low organic matter contents, very fine textures and adverse climatic conditions.

The soils of British Columbia which have the greatest potential for damages to be incurred are those that belong to the Gray Luvisol order and those being cleared under very humid conditions.

It has been hard to estimate the actual extent to which soil degradation through land clearing has occurred. Individual cases and examples easily come to mind, but to summarize in a provincial sense is almost impossible due to the lack of reputable information.

In light of the amount of land that has been brought into production from forests in this province, this author tends to feel that the overall extent and degree of soil degradation is low.

Table 1

AREA OF CROP AND IMPROVED FARMLAND 1901-1981*

(hectares)

Census year	1901	1911	1921	1931	1941	1951	1961	1971	1981
Improved Farmland+	191,744	193,356	220,430	285,407	361,573	464,687	527,637	710,626	946,733
Area in Crops++	73,606	115,034	158,574	204,637	238,515	272,246	319,391	442,345	568,483

*Source - Agricultural Statistics Yearbook, B.C. Ministry of Agriculture and Food (November 1982) and Agriculture Statistics Division, Statistics Canada, 1951.

+ Improved farmland is defined as the total of four agricultural land use categories: crop land, improved pasture, summerfallow and other improved land. "Other improved land" includes barnyards, gardens, farm roads and lanes, idle farmland and areas of unseeded new breaking.

++ Area in crops is defined as that area planted or to be planted in the census year.

Table 2

PROVINCIAL GROWTH RATES OF CROP AND IMPROVED FARMLAND

	% Increase
1901 - 1981	
Improved Farmland	394
Area in Crops	672
1971 - 1981	
Improved Farmland	33
Area in Crops	29

Table 3

PROVINCIAL AND REGIONAL GROWTH RATES OF

IMPROVED FARMLAND 1971-1981

Region	Hectares 1971	1981	% Increase
Kootenay	30,383	36,300	19
Okanagan	91,711	104,003	13
Thompson	58,354	102,128	75
Mainland	77,377	81,131	5
Vancouver Island	21,989	25,768	17
Cariboo	54,933	90,988	66
Central	67,740	129,025	90
Peace River	308,140	377,390	22
Province	710,626	946,734	33

Table 4

PROVINCIAL AND REGIONAL GROWTH RATES

OF TOTAL AREA IN CROPS 1971 - 1981

Region	Hectares 1971	Hectares 1981	% Increase
Kootenay	21,417	22,794	6
Okanagan	56,139	61,379	9
Thompson	30,222	37,504	24
Mainland	43,971	54,643	24
Vancouver Island	11,200	15,628	40
Cariboo	29,039	45,895	58
Central	40,190	69,988	74
Peace River	210,166	260,652	24
Province	442,344	568,483	29

Table 5

LAND CLEARED UNDER THE AGRICULTURE

LAND DEVELOPMENT ACT (ALDA) 1946-1982

(Hectares)

	1946-1964	1965-1982	1946-1982
Peace	24,099	43,057	67,156
Central	12,795	21,119	33,914
Cariboo	6,005	7,143	13,148
Lower Mainland & Island	5,589	3,203	8,792
Okanagan	3,547	3,507	7,054
Kootenays	2,406	1,892	4,298

PROVINCIAL TOTAL - 134,362

Table 6

PERCENT OF TOTAL LAND CLEARED UNDER ALDA FOR TWO 18 YEAR PERIODS

Region	1946-1964	1965-1982
	Percent (%)	
Peace	36	64
Central	38	62
Cariboo	46	54
Lower Mainland & Islands	64	36
Okanagan	50	50
Kootenays	56	44

REFERENCES CITED

Allison, F.E. 1973. Soil Organic Matter and Its Role in Crop Production. Developments in Soil Science 3, Elsevier Scientific Publishing Company, 637 p.

Dickerson, B.P. 1976. Soil Compaction After Tree Length Skidding in Northern Mississippi. Soil Sci. Soc. Amer. J. 40(6):965-966.

Feller, M.C. 1982. Soil and Other Considerations in Slashburning. In Soil Interpretations for Forestry, A.P.D. Technical Paper 6, Land Management Report No. 10, B.C. Ministries of Environment and Forestry.

Jorgensen, J.R., and C.G. Wells 1971. Apparent Nitrogen Fixation in Soil Influenced by Prescribed Burning. Soil Sci. Soc. Amer. Proc. 35(5):806-810.

Lowe, L.E., and A.A. Bomke 1982. The Windrow Effect Following Land Clearing in the Prince George Area. Preliminary Study - British Columbia Agricultural Science Coordinating Committee.

Mason, J.L., W.K. Dawley and M. van Adrichem 1976. Plant Analysis of Grass Forage from Outside and Inside a Burned Tree Windrow made in Clearing the Land. Unpublished Report to B.C. Land Resource Science Lead Committee.

Pritchett, W.L. 1979. Properties and Management of Forest Soils. John Wiley and Sons, 500 p.

Ralston, C.W., and G.E. Hatchell 1971. Effects of Prescribed Burning in the Physical Properties of Soils. p 68-86. In Proc. Prescribed Burning Symp. U.S.D.A. For Serv., SE For. Exp. Sta., Asheville.

Statistics Canada 1951. Ninth Census of Canada - Agriculture.

Statistics Canada 1981. Twelfth Census of Canada - Agriculture.

Wells, C.B. 1971. Effects of Prescribed Burning on Soil Chemical Properties and Nutrient Availability p. 86-89. In Proc. Prescribed Burning Symp. U.S.D.A. For. Serv., SE For. Expt. Sta., Asheville.

Wood, C. 1983. Personal Communication.

REFERENCES ON ASSOCIATED TOPICS

Anderson, C.H., and C.R. Elliot 1957. Studies on the Establishment of Cultivated Grasses and Legumes on Burned Overland in Northern Canada. Can. J. Plant Sci. 37:97-101.

Beamish, J.E. 1950. Land Clearing for Agriculture in British Columbia. Bulletin 85 Ag. Engineering Div., Development and Extension Branch, B.C. Department of Agriculture, 49 p.

Dobb, J.L. 1963. Land Development in the Peace River. Vol. 9, No. 1, Agriculture Canada.

Friessen, H.A., M. Paston, W.G. Corns, J.L. Dobb and A. Johnston 1965. Brush Control in Western Canada. Publication 1240 - Agriculture Canada.

Guitard, A.A., J.D. Dobb and A.M.F. Hennig 1964. Clearing, Breaking and Initial Cropping of Northern Bushlands. Agriculture Canada, Research Highlights, Beaverlodge, Alberta.

Hennig, A.M.F. 1963. Soil Horizons, Vol. 4, No. 2, June.

Hennig, A.M.F. 1965. The Effects of Methods Used to Break Virgin Wooded Soils on the Yields of Wheat and Flax. Can. J. Soil Science Vol. 45:281-288.

Preston, S.G. 1952. Tillage Investigations in Central British Columbia. In Report of the B.C. Agronomists Association Conference, Vancouver 1952:84-86.

Pringle, W.L., C.R. Elliot and J.L. Dobb 1973. Aspen Regrowth in Pastures of the Peace River Region. Jour. Range Manag. 26(4):260-262.

Research Highlights Agriculture Canada 1957. Beaverlodge - Study of Breaking Methods p. 17-18.

Young, J.R.W. 1951. Some Tillage Problems in British Columbia. In Report of B.C. Agronomists' Association Conference, Vancouver 1951:52-55.

SOIL DEGRADATION EFFECTS OF FOREST HARVESTING AND SITE PREPARATION

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INTRODUCTION

Soil degradation caused by forest harvesting or site preparation is of concern for several reasons. It may result in problems elsewhere, e.g. through degradation of water quality. It may reduce site productivity. And low revenues from forest land may preclude ameliorating these effects, so that some kinds of degradation may tend to be long-lasting.

A management practice which causes soil degradation is not necessarily inappropriate or unwise. The social values of a forest are realized through production of timber, water, wildlife, forage, recreation and aesthetics. An effect of forest soil disturbance is called "degradation" when it tends to reduce the production of these social values, even if it may be accompanied by beneficial effects. We pay for various forest values in terms of money spent, opportunities foregone, and other costs. A cost paid in terms of soil degradation, to obtain certain forest values, is not necessarily higher than the cost of avoiding such degradation, whether the latter cost is measured in dollars spent or in opportunities and benefits foregone.

The objective of this paper is only to discuss the soil degradation occasioned by timber harvesting and site preparation practices, without fully considering the benefits or judging the appropriateness of such practices.

SOIL DEGRADATION CAUSED BY TIMBER HARVESTING

In looking at timber harvesting effects, we are sometimes compelled to measure soil disturbance objectively and infer degradation subjectively.

Mineral soil exposure, which may lead to accelerated erosion, is an example of such disturbance.

A study in the Nelson Forest Region found that the fraction of the land area disturbed by roads amounted to about 40% with summer ground skidding; 21% with winter ground skidding; about 11% with summer high-lead yarding; 22 and 27% with winter and summer grapple yarding, respectively; about 8% with summer jammer yarding; and none with summer skyline yarding (Smith and Wass 1976). On unburned sites, only about 5% of the area between skidroads was occupied by exposed mineral soil.

A study in the Vancouver Forest Region found exposed mineral soil (off-roads) ranged from 5 to 56% of the area where high-lead yarding had taken place (Bockheim, Ballard and Willington 1975). The average was 29%. The lowest values were found where yarding occurred over snow or where special care was taken to minimize disturbance. The greatest disturbance was found on slopes exceeding about 34 degrees. The same study examined two tractor-logged areas, one on a 25-percent slope; the other on a 60-percent slope. Both had about 70% of the area (off the main haul roads, but including skid trails) occupied by exposed mineral soil. On the 25-percent slope, part of the area had been tractor-logged; the remainder had been subject to high-lead yarding: mineral soil exposure amounted to 21 and 71% of the areas, respectively. On a helicopter-logged site, only 5% of the area was occupied by exposed mineral soil.

A study in the Skeena District of the Prince Rupert Forest Region (J. Schwab, unpublished manuscript) found that 59% of the area on tractor skidroads was subject to erosion processes, compared with only 7.5% of the logged area off skidroads. On sites where high-lead yarding was used, only 3.1% of the area was subject to erosion. Soil on 43.8% of the area logged with crawler tractors was subject to gouging resulting in mineral soil exposure, compared with 22.1% where skidders were used. Where high-lead yarding was used, mineral soil was exposed on only 17.0% of the area.

The forester may not wish to minimize mineral soil exposure, because it can be desirable for regeneration of several tree species after logging. Whether mineral soil exposure leads to degradation is largely a matter of factors influencing erosion. Soil texture, structure, slope angle, and slope length are important factors, as recognized in the Universal Soil Loss Equation of Wischmeier and Smith (1960). The forester wanting exposed mineral

soil for regeneration requires it patchily but well distributed over the area. If the affected areas are elongated and continuous downslope, as may be the case with many high-lead yarding channels and tractor skid-trails, regeneration benefits may be present, but the tendency for channeled runoff and enhanced erosion risk may be high. Often, exposure of mineral soil is accompanied by such processes as compaction, puddling, and pore-clogging, which may dramatically reduce infiltration capacities, tending to increase the risk of local surface runoff and erosion.

Exposure of mineral soil changes the soil thermal regime. However, as it tends to reduce surface temperature maxima, which might be damaging or even lethal, while raising subsurface temperatures within the root zone (Ballard, Black, and McNaughton 1977), it is probably rare that the thermal effect would be considered a form of degradation.

Timber harvest occurs infrequently, so that there may be a long recovery period after degradation occurs. However, where intensive management is practiced, pre-commercial and repeated commercial thinning may lead to more frequent physical impacts, and more serious consequences.

In steep terrain, timber harvesting may result in greater frequency and extent of mass soil movement. Tree roots growing through the shear plane contribute to soil shear strength, and positive pore water pressure reduces the frictional contribution to soil shear strength (Swanston 1970). Decay of root systems may contribute substantially to increased incidence of shear failures several years after timber harvest (Bishop and Stevens 1964; O'Loughlin 1972). Collection and diversion of water by road drainage systems may result in unprecedented water concentration on some parts of the slope, resulting in higher pore water pressure and increased risk of slope failure. Although the land area affected by such problems may be only a very small fraction of the total, the values threatened are substantial in some localities.

Soil fertility may be gradually degraded by losses of nutrients in harvested crops. For example, with whole-tree logging, about 300 to 500 kg of nitrogen per hectare may be removed by clearcutting a conifer stand at rotation age. Conventional logging, which leaves the slash behind and removes only bole wood and bark, may take about 12 to 350 kg of nitrogen per hectare. Analogous losses of various magnitudes occur with the other nutrients.

Nutrient losses may be more or less replaced naturally through biological nitrogen fixation, weathering, and precipitation inputs.

Nitrogen deficiency appears to be overwhelmingly the most important nutritional limitation in B.C. forests currently (Ballard 1981, 1982). However, inspection of data obtained by the University of Washington, on glaciated terrain resembling that of southwestern B.C., suggests that only a few rotations of timber harvesting could lead to severe potassium limitations, unless exchangeable potassium can be rapidly restored by weathering (Cole, Gessel and Dice 1967). Thus we can expect that nutritional problems on forest land and our concerns about soil degradation caused by harvesting may change as forestry progresses from harvesting of old-growth timber to repeated cropping of managed forests.

Timber harvesting can also affect leaching losses of nutrients. University of Washington data (Cole and Gessel 1965; Gessel and Cole 1965) showed that in the first year after clearcutting of a second-growth Douglas-fir stand, leaching of N from the root zone increased by 81%; K, about 200%; and Ca, 115%. But for all three nutrients, even after clear-cutting, the annual loss was no more than 1% of the organic and exchangeable forms of these nutrients. During plant succession after logging, the leaching losses may quickly revert to something like the pre-harvesting levels. Consequently such increased losses, occurring only once every 60 to 80 years, may not be very serious. The same study found that over a 10-month period following clearcutting, P leaching increased by about 230%. However, the loss was only about 0.1 kg/ha over this period, a magnitude too small to be of much concern.

SOIL DEGRADATION CAUSED BY SITE PREPARATION

Site preparation to facilitate forest regeneration may be employed soon after harvesting. In some cases, the specific method used is chosen not only to enhance seedling survival and early growth, but to improve ease of planting and/or to abate fire hazard.

Where heavy accumulations of logging residue occur, slashburning is commonly considered. Hydrolysis of the base oxides from ash causes a rise in

soil pH. If much ash is involved and the soil is poorly buffered, the rise may be extreme, but relatively transient. In soil with higher buffering capacity, a smaller, but more lasting rise in pH occurs (Beaton 1953). The pH change is not necessarily degradation. In many cases, surface soil pH before burning is about 3.5 to 4.0, and burning results in a more favorable pH for trees. Even when an excessive pH results, it may be so transient that by the time planting occurs, it is no longer a problem. Perhaps the most serious pH problem caused by slashburing occurs where soils are derived from calcareous materials; in such cases, post-burning pH may sometimes persist at levels excessive for the preferred species.

As much as 60% of the S and 80% of the N in a forest fuel may be lost by volatilization during combustion (Allen 1964; Debell and Ralston 1970). Precipitation inputs and weathering may restore some of the S, and nitrogen fixation as well as precipitation inputs may restore some of the N lost from the terrestrial biological nutrient cycle. Another consideration is that some losses of these elements may occur even if the slash is not burned. Despite such factors which may lessen the relative impact of burning, the predicted losses are large enough to cause concern. This is particularly so on much of B.C. forest land, where nitrogen is already seriously deficient; on some of this land, if the nitrogen deficiency were removed, sulfur would be the next most serious growth-limiting nutritional factor (Ballard 1981, 1982).

Logging residues and surface humus play important hydrologic roles. They tend to reduce overland flow and trap sediment. Thick mor humus also has significant water retention capacity, affecting stream hydrographs and providing available water for plant growth. Particularly on lithic Folisol areas, the loss of organic matter by burning may have serious effects on the site water regime, as well as on nutrient reserves and potential root zone thickness.

Water repellency of soils may be induced or aggravated by burning. This phenomenon has been particularly well studied in the southwestern U.S. (DeBano and Letey 1969), but it has also been observed in British Columbia (Bockheim, Ballard, Willington, and Larson 1973). A forest soil which before burning has an infiltration capacity far in excess of the highest recorded local rainfall intensity can be converted by burning into a material with only

a few millimetres of water retention capacity over a non-wettable layer. Runoff from such an area may cause locally catastrophic erosion. The distribution, seriousness, and longevity of fire-induced hydrophobicity in western Canada deserves more study.

Burning may also affect the soil temperature regime. A fire-blackened surface tends to absorb more short-wave radiation, leading to high daytime surface temperature, if a relatively thick organic layer remains. Relatively complete reduction of the organic layer may result in more heat transfer into the mineral soil and no great increase in surface temperature maxima, despite surface blackening (Ballard, Black, and McNaughton 1977).

Mechanical site preparation is sometimes carried out to obtain the benefits of exposed mineral soil for regeneration. For some species, this practice is often considered desirable where harvesting has exposed little or no mineral soil (e.g., winter-logged areas) or where burning is inappropriate. Small scalps may provide thermal benefits and enhance survival and early growth of planted seedlings, while minimizing erosion susceptibility and keeping the removed nutrients close enough to be exploited by the extending seedling root system. Nitrogen, available sulfur (Will and Youngberg 1978) and extractable phosphorus (Bockheim et al. 1973) may be particularly associated with the surficial organic or organic-rich layers. In contrast with the small scalps, more extensive areas from which surficial materials are removed may lead to nutritional and erosion problems.

In the Central Interior, mechanical site preparation is often contemplated for relatively wet sites, where machinery operation may lead to puddling, compaction, and other processes which tend to aggravate the poorly drained and poorly aerated soil conditions which impair growth and metabolism of tree roots. Time constraints, work loads and available equipment inventories sometimes leave the forester with a less-than-optimal site preparation option. In such cases, if productivity would be limited more by failure to enable prompt regeneration than by some soil degradation, the choice is clear: accept some soil degradation. In many cases, however, the damage could be avoided, or at least minimized, by scheduling work on susceptible soils for the driest season, and using the least damaging equipment.

SOIL DEGRADATION IN THE FOREST REGIONS OF BRITISH COLUMBIA

How serious and how extensive are various kinds of forest soil degradation associated with timber harvesting and site preparation in British Columbia? No systematic inventory has been attempted, but a questionnaire was sent to the Regional Pedologists of the Ministry of Forests asking for at least some subjective estimates. The replies were so different that it is impossible to tabulate results for purposes of comparisons among the six regions. A full presentation of the responses would take several pages, so only a condensed summary follows.

In Kamloops and Cariboo Regions, timber harvesting impacts in terms of compaction, puddling, and surface erosion were rated relatively important, where skidroads and landings but no main haul roads were included in the evaluation. Several percent of the harvested area was regarded as subject to moderate or severe impacts of these kinds. Significant nutrient losses occasioned by harvesting were perceived not only there, but also in the Vancouver Forest Region. Replies from the Kamloops and Vancouver Regions mentioned interception of subsurface water flow by road systems as an important impact. Unfortunately, comments on this problem had not been specifically solicited in the questionnaire, so its significance in other regions is not known.

In relation to slashburning, nutrient losses were perceived as the major concern, with either erosion or hydrophobicity as the second-ranked impact. Compaction, puddling, erosion losses, and nutrient redistribution were all recognized as major concerns in relation to mechanical site preparation in the Kamloops and Cariboo Regions. However, mechanical site preparation is used little in Cariboo Region and hardly at all in Vancouver Region.

As might be expected, evaluations for the Nelson Region tended to resemble those for the Cariboo and Kamloops areas, and there were specifications of particularly susceptible soils. For example, puddling during harvesting operations was recognized as an important concern with Luvisols in the East Kootenays. Nutrient losses and redistributions were considered particularly important with coarse-textured soils. And degradation caused by mechanical site preparation on calcareous soils was identified, presumably because calcareous material may be exposed at the surface, with detrimental effects on nutrition and growth.

Mass soil movement is recognized as a local concern in several regions, but is probably most serious in the Prince Rupert Region, notably in the Queen Charlotte Islands. Prince Rupert and Prince George Regions sent no area estimates of soil degradation. Areas subject to harvesting, burning, and mechanical site preparation could be tallied, but the severity and extent of consequent soil degradation could not be even approximately guessed. Prince Rupert Region, for example, has a forest area of about 31 million hectares. Annually there, about 0.09% of the area is harvested, 0.016% is slashburned, and 0.012% is subject to mechanical site preparation. Clearly, if recovery from degradation begins soon after the immediate impact, the proportional extent of serious soil degradation cannot be very great, and even the absolute extent is not extremely large.

Kamloops Region offers an interesting contrast. It has a total of 5.5 million hectares, about 0.4% of the area is subject to harvesting annually, and the more important kinds of degradation caused by harvesting are rated moderate or worse in severity on from 7 to 40% of the annually affected area. This amounts to about 1,700 to 10,000 hectares per yer, depending on the kind of degradation involved. Annually, about 8,000 hectares are slashburned and 2,000 hectares mechanically treated in Kamloops Region. Productivity losses occasioned by forest practices are inferred to be particularly great in relation to nutritional impacts and compaction.

Although some respondents attempted to guess productivity losses caused by soil degradation, regional comparisons are problematic because of the different assumptions used. In a situation where even short-term impacts are very difficult to estimate semi-quantitatively, we lack altogether the evidence needed to infer long-term implications of practices applied only once in a period of 80 years. Also, once the road systems are in and the large, old-growth timber has been removed, subsequent impact of forestry practices might be rather different. Access-related impacts may be minor, yarding impacts may be less, residue accumulations requiring treatment may be fewer, and the amount of surficial humus may be less on many sites when the next timber harvest takes place. So we cannot extrapolate from present experience and forecast similar impacts in perpetuity.

OVERVIEW AND CONCLUSIONS

The foregoing paper has identified some kinds of soil degradation which may be of particular concern where timber harvesting and site preparation are carried out on forest land. In most cases, only subjective estimates are available to assess the severity and extent of impacts. Despite their subjectivity, such estimates are useful because they identify the specific problems and the geographical areas where more objective evaluations might be worthwhile.

Perhaps we need, first of all, a set of simple methods usable for making such evaluations: methods which would be quick, easy, and inexpensive to use on large areas characterized by great variability of soils and treatment intensities.

Without such methods, we cannot dependably quantify the soil degradation associated with our management practices, and neither the weighing of costs and benefits nor the choice among managment options can be based on convincing evidence.

Measurement of degradation is only part of the task, however. Uness we can predict, on a site-specific basis, the degradation which would be caused by alternative treatments, we shall be powerless to make a good management decision in advance; we shall only be able to quantify our mistakes. Perhaps too many studies have been designed to quantify degradation on a particular research site, without paying enough attention to research design which would facilitate extrapolation of results to other sites.

Concern about compaction, puddling, and other structural damage caused by harvesting and mechanical site preparation is sufficient to indicate that season of operations and choice of equipment must be guided in part by such considerations as soil texture and soil moisture regime. Unnecessary nutrient losses associated with harvesting practices, slashburning, and mechanical site preparation should be avoided where possible. These are perhaps the most important concerns, but there are several others, some of which may be paramount on particular sites. Degradation caused by harvesting and site preparation must be viewed in perspective with road-related impacts and impacts of other management practices, to ensure that ameliorative investments in forestry will be allocated where they will do the most good.

We cannot condemn forest practices merely because they cause soil degradation. The appropriateness of forest practices can only be determined by comparing costs and benefits of different management options.

At this stage, we cannot claim to know many of the answers. But perhaps we are beginning to understand the questions.

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LITERATURE CITED

Allen, S.E. 1964. Chemical aspects of heather burning. J. Appl. Ecol. 1:347-367.

Ballard, T.M. 1981. Foliar analysis research. Contract Res. Report to Research Branch, B.C. Min. For. 132 pp.

Ballard, T.M. 1982. Foliar analysis research. Contract Res. Report to Research Branch, B.C. Min. For. 19 pp. (+Appendices: 258 pp.)

Ballard, T.M., T.A. Black, and K.G. McNaughton. 1977. Summer energy balance and temperatures in a forest clearcut in southwestern British Columbia. In: 6th B.C. Soil Science Workshop Report, B.C. Min. Agr., Victoria, pp. 74-86.

Beaton, J.D. 1953. Influence of burning on the soil in the timber range area of Lac le Jeune, B.C. Unpubl. M.S. Agr. thesis, Univ. of B.C., Vancouver. 113 pp.

Bishop, D.M. and M.E. Stevens. 1964. Landslides on logged areas in southeast Alaska. U.S. For. Serv. Res. Pap. NOR-1. 57 pp.

Bockheim, J.G., T.M. Ballard, and R.P. Willington. 1975. Soil disturbance associated with timber harvesting in southwestern British Columbia. Can. J. For. Res. 5: 285-290.

Bockheim, J.G., T.M. Ballard, R.P. Willington, and J.L. Larson. 1973. Impact of clearcutting on soils and watersheds, southwestern British Columbia.

Contract Research Report to Pacific Forest Research Centre, Canadian Forestry Service, Victoria. 262 pp.

Cole, D.W. and S.P. Gessel. 1965. Movement of elements through a forest soil as influenced by tree removal and fertilizer additions. In: C.T. Youngberg (ed.) Forest-soil relationships in North America. Ore. State Univ. Press, Corvallis. pp. 95-104.

Cole, D.W., S.P. Gessel and S.F. Dice. 1967. Distribution and cycling of nitrogen, phosphorus, potassium and calcium in a second-growth Douglas-fir ecosystem. In: Symp. on Primary Productivity and Mineral Cycling in Natural Ecosystems. Univ. Maine Press, Orono. pp. 197-232.

DeBano, L.F. and J. Letey (eds.). 1969. Water repellent soils. Proc. Symp. Water Repellent Soils. Univ. of California, Riverside. 354 pp.

DeBell, D.S. and C.W. Ralston. 1970. Release of nitrogen by burning light forest fuels. Soil Sci. Soc. Am. Proc. 34:936-938.

Gessel, S.F. and D.W. Cole. 1965. Influence of removal of forest cover on movement of water and associated elements through soil. J. Am. Water Works Assoc. 57: 1301-1310.

O'Loughlin, C.L. 1972. An investigation of the stability of the steepland forest soils in the Coast Mountains, southwest British Columbia. Unpubl. Ph.D. thesis, University of British Columbia, Vancouver. 147 pp.

Smith, R.B. and E.F. Wass. 1976. Soil disturbance, vegetative cover and regeneration in clearcuts in the Nelson Forest District, British Columbia. Can. For. Serv., Pac. For. Res. Centre, Publ. BC-X-151. 37 pp.

Swanston, D.N. 1970. Mechanics of debris avalanching in shallow till soils of southeast Alaska. U.S. For. Serv. Res. Pap. PNW-303.

Will, G.M. and C.T. Youngberg. 1978. Sulfur status of some central Oregon pumice soils. Soil Sci. Soc. Am. J. 42:132-134.

Wischmeier, W.H. and D.D. Smith. 1960. A universal soil-loss equation to guide conservation farm planning. 7th Int. Congr. Soil Sci., Madison, Wisconsin. VI, 2:418-425.

ACCESS ROAD RELATED DEGRADATION PROBLEMS IN FORESTRY

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1.0 Introduction

Forest road building and timber harvesting activities have been shown to be primary causes of soil degradation in the forest environment. Forest road building has been recognized as the principle agent in accelerated surface and mass erosion on forested land (3, 5, 13, 14, 19, 20, 21). Additionally, construction of skidroads and landings for yarding access can lead not only to soil erosion but also reduced forest productivity through scarification and compaction (4, 5, 22, 23, 24, 25, 26).

The results of a 1981 Ministry of Forests Survey of the percent of cut-over area occupied by skidroads, landings, and haul roads are presented in Table 1 (based on internal memos). There is a wide range in the estimates for each category from various regions. This is to be expected, particularly for the skidroad and landings. Regional terrain, season of logging, and predominant logging method influence the percent disturbance on cut-over land. The interior regions (Prince George, Kamloops, Cariboo, Nelson, and part of Prince Rupert) are dominated by ground-based logging which requires more skidroads and landings than cable logging. However, one would not expect the interior regional esimates to differ so greatly. Except for the Cariboo Region, the other estimates appear very conservative. This can be demonstrated using the Nelson Region as an example.

Table 2 presents a comparison of percent area occupied on cut-over lands by skidroads, landings, and haul roads from three sources. The Ministry of

TABLE 1

PERCENTAGE OF AREA ON CUT-OVER LANDS

REGION	SKID-ROAD	LANDING	HAUL ROAD
CARIBOO	16	4	3
PRINCE GEORGE	4	5	3
KAMLOOPS	2	1	2.5
NELSON	10	2	5
PRINCE RUPERT			
DRY-BELT	4	4	5
WET-BELT	0	0.7	2
VANCOUVER	0	1.2	4

TABLE 2

PERCENTAGE OF AREA ON CUT-OVER LAND
(COMPARISON)

	SKID-ROAD	LANDING	HAUL ROAD
NELSON REGION			
M.O.F.	10	2	5
C.F.S.			
SUMMER	25	7.6	6.5
WINTER	14.4	4	3
PAC. NORTHWEST	20-35		

Forests estimate is from the regional headquarters (internal memo 1981), the C.F.S. estimate is from Smith and Wass (1979), and the Pacific Northwest estimate summarized from Dyrness (1965), Lull (1959), Steinbrenner (1955), Steinbrenner and Gessel (1955), and Froehlich (1973). The Ministry of Forests estimate is approximately half of the C.F.S estimate for the same region. The C.F.S. data compares favourably with the Pacific Northwest estimates. This comparison points out the conservative nature of the Ministry of Forests estimates.

Using the Ministry of Forests estimates and combining them with the area clear cut over the 1970's, the amount of land involved is still substantial (Table 3). From 1971-1980, approximately 47,500 ha have been removed from forest production by road construction. While being necessary for all phases of forest management, this still represents a considerable area subject to erosion processes. An additional 110,000 ha have been severely degraded due to skidroad and landing construction, resulting in reduced forest productivity. Although skidroads and landings are subject to soil erosion, as are haul roads, they will be discussed in this paper only in terms of reduced production capability.

2.0 Road-related Erosion

2.1 Introduction

Forest roads have been recognized as a major source of sediment through both surface and mass erosion. Some possible causes include (13):

1. reduction of protective cover;
2. destruction or impairment of natural soil structure or fertility;
3. increased slope gradients caused by road construction;
4. decreased infiltration rates caused by road cutslopes;

TABLE 3

AREA OCCUPIED ON CUT-OVER LAND
1971-1980
(000 HA)

REGION	SKID-ROAD	LANDING	HAUL ROAD
CARIBOO	31.2	8.2	5.9
KAMLOOPS	2.8	1.4	3.5
NELSON	12.4	2.5	6.3
PRINCE GEORGE	17.3	22.0	13.0
PRINCE RUPERT	4.5	5.1	7.8
VANCOUVER	0	3.3	11.0
TOTAL	68.2	42.3	47.5

5. interception of subsurface flow by road cutslopes;
6. decreased shear strength, increased shear stress, or both on cut and fill slopes;
7. concentration of generated and intercepted water.

There are five major sources of sediment from forest roads (19):

1. sediment from sidecast during (and after) construction;
2. road surface wash;
3. road cutslope sediment transported by ditch flow;
4. landslides commonly initiated in road fill or sidecast materials;
5. sediment that is stored in stream channels (or gulleys) that is mobilized during mass erosion events (i.e., landslides, debris flows, or debris avalanches).

Sources 1, 2, and 3 are associated with surface erosion, while 4 and 5 are associated with mass erosion events.

2.2 Road-related surface erosion

Surface erosion resulting from forest road construction is a major management-related cause of forest stream turbidity and sedimentation (1). This is particularly true during the first few years following road construction. Fredricksen (1965) and Dyrness (1970) found erosion rates to be greater the first year following construction than in subsequent years.

The sediment produced by eroding road slopes not only degrades the physical quality of stream waters, but may also adversely affect road stability (7). Eroded material can reduce the drainage capacity of road ditches and culverts, undercut road banks, and undermine the road surface itself. This being the case, surface erosion from forest roads can be a causative factor in road mass erosion events.

2.3 Road-related mass Erosion

Road building is widely recognized as one of the primary causes of mass erosion in managed forest land (21). Several studies conducted on forested slopes in the western U.S. indicate that road construction was responsible for between 60 and 90% of all mass failures (14, 15, 19, 21). A landlside inventory conducted by the U.S.F.S. in Oregon and Washington following the 1964-1965 winter floods indicated that road-related mass failures were involved in approximately 60% of the damage reports (21). In a similar inventory conducted on the South Fork of the Salmon River in Idaho, only 9 out of 89 landlsides were not road associated (14). A similar proportion of road-related landslides (88%) was found in a 1974-76 survey of 1,418 landslides on the Boise and Clearwater National Forests (15). Reid et al. (1981) concluded that landslides were responsible for approximately 60% of road-related sediment production in the Clearwater River basin of Washington.

2.4 Road-related erosion control

Logging roads have long been recognized as a primary cause of accelerated erosion and sedimentation in the forest environment. Fortunately, there are a variety of practices available that can reduce the erosional impacts of forest road construction. Such measures are based on four basic principles (13):

1. minimize the amount of disturbance caused by road construction by:
   a. controlling the total mileage of roads
   b. reducing the area of disturbance on roads that are built;
2. avoid construction in high erosion hazard area;

3. minimize erosion on areas that are disturbed by road construction by a variety of practices designed to reduce erosion;
4. minimize the off-site impacts of erosion.

Principles 1 and 2 are self-explanatory. Practices applicable to principle 3, reducing erosion from areas that are disturbed by road construction, have been summarized in A Handbook for Roadside Erosion control in British Columbia (Carr 1980). These practices deal primarily with a combination of site preparation and revegetation (also known as bioengineering). Principle 4, minimizing off-site impacts of erosion, recognizes that all erosion from forest roads cannot be controlled. In such cases, one must rely on downslope sediment storage to reduce movement of eroded material into an active drainage system (13).

Haupt (1959) and Packer (1967) recognized the importance of a filter/buffer strip and the obstructions within it in protecting intervening slopes, other downhill roads, and stream channels from road-originated sediment. The number, spacing, and type of obstructions are the key factors involved in buffer strip width determinations (10, 17). Packer (1967) concluded that the width of a protective buffer strip can be substantially reduced by installing effective slope obstructions, such as logs, and spacing them closely. The installation of log terraces in the Bend, Oregon municipal watershed has proven to be highly effective in trapping sediment as it moves downhill (12).

Adherance to the four basic principles as put forth by Megahan (1977) should minimize the impact of forest road construction on stream sedimentation. However, diligent road maintenance, particularly of drainage structures, is necessary to insure continual erosion control throughout the life of a road

system. Additionally, once the road is no longer in use, proper road closure procedures as put forth by Megahan (1977) are manditory to help assure that the road does not become a future erosional problem.

3.0 Landing and Skidroad Degradation

3.1 Effect on forest productivity

The amount of area occupied by skidroads and landings is substantial. Referring back to Table 3, the estimate for the 1970's was approximately 110,000 ha (or on annual increment of 11,000 ha). Skidroads, which can occupy up to 32% of the cut-over land, are often scarified to a depth greater than 25 cm (22). Landings, which may occupy an area as large as 0.5 ha, are usually scarified to depths greater than 1.0 m. Although both are subject to compaction, landings receive more severe treatment due to continual equipment operation.

The negative impacts of landing and skidroad construction on the soil are:

1. nutrient removal during scarification (22, 25);
2. increased bulk density, ranging from 15-20% (4, 5, 9, 24, 26);
3. decreased infiltration, ranging from 35-93% (24, 25);
4. loss of macropore structure, ranging from 10-68% (4, 24, 25);
5. decrease in micropore space (4).

The resulting effects on the forest productivity on these sites are:

1. regeneration delay, ranging from 3-12 years (4, 22, 26);
2. reduced stocking (24, 26);
3. poor tree vigor (24);

4. reduced tree growth, ranging from 6-14% (9, 22, 24, 25, 26);
5. volume reduction, prorated over the entire cut-over area, ranging from 12-15% (9, 22, 26).

Obviously, the reduced productive capacity of skidroads and landings represents a form of internal land alienation from the forest land base. Corrective measures for soil decompaction and nutrient retention or enhancement must be incorporated into management policy.

3.2 Landing and skidroad rehabilitation policy

The Ministry of Forests is directed to maintain and improve the forest and range resources of the province. Soil is the fundamental resource to be preserved in the case of landing and skidroad construction and rehabilitation. Over the past five years, all forest regions have instituted a landing policy that deals not only with landing construction but also rehabilitation. Most of the regional policies are based on the Cariboo Regional policy, the first regional landing policy in the province. A summary of the rehabilitation measures are (16):

1. ripping or scarification to a depth of 30 cm, if deemed necessary;
2. burning of slash piles;
3. respreading of topsoil and ash pile on the landing.

These measures are aimed at soil decompaction and restoration of soil nutrients.

Unfortunately, a policy is not effective unless properly adhered to or enforced. The results of a 1981 survey of landing rehabilitation in the Cariboo Region revealed the following (16):

1. poor landing location resulted in excessive site disturbance;
2. topsoil was removed and seldom respread;
3. scarification did not always conform to policy, only 8% in the IDF (B) subzone while 90% in the S.B.S. zone;
4. compaction reduced only at the soil surface, compaction remained high below 15 cm;
5. slash disposal conformed to policy except where dirty piles reduced the effectiveness of the burn;
6. planted spruce did not appear healthy and were growing poorly.

Among the recommendations of Mitchell's survey, the following pertain to landing rehabilitation (16):

1. restrict the size of landings to reduce the rehabilitation problem;
2. push topsoil into one retrievable pile;
3. pile and burn slash away from topsoil;
4. up compacted surfaces to a depth of 20 cm;
5. spread the ashes and topsoil as evenly as possible over the landing;
6. plant landings with hardy stock (i.e., lodgepole pine);
7. maintain accurate and current information on all areas;
8. enforce the landing guidelines.

Based on these recommendations, a new landing policy is being drafted for the Cariboo region. Additionally, the Research Branch is investigating the practice of deep ripping (50 cm) and the use of legumes in landing rehabilitation (E.P. 834: 07). The deeper ripping allows for a greater unrestricted rooting zone for regeneration. The use of legumes may

assist in the recovery of nitrogen lost from the site during scarification or slash burning. The results from this work should be available in 1983-84.

4.0 Summary

There is no doubt that forest access results in a large amount of soil degradation. Haul roads contribute greatly to accelerated surface and mass erosion in the forest environment. Landings and skidroads are not only subject to erosion processes but may also result in reduced productive capability. The magnitude of these problems can be reduced and the negative impacts on the forest environment alleviated if preventative and corrective measures are applied.

The scale of surface and mass erosion resulting from forest roads can be greatly reduced through proper planning, the use of high construction standards, efficient road maintenance, and eventual road closure. Although some modification may be necessary, stricter enforcement of landing construction and rehabilitation policies will reduce the scale of soil degradation and promote the full recovery of forest productivity. Given due consideration, the soil degradation problems associated with forest access can be minimized to an acceptable level.

Bibliography

1. Berglund, E.R. 1976. Seeding to control erosion along forest roads. O.S.U. Extension Service, Corvallis, Oregon. 19 pp.

2. Carr, W.W. 1980. Handbook for forest roadside surface erosion control. Land Management Report Number 4, B.C. Ministry of Forests, Victoria. 43 pp.

3. Carr, W.W. and T.M. Ballard. 1980. Hydroseeding of forest roadsides in British Columbia for erosion control. J. of Soil and Water Conservation 35(1): 33-35.

4. Dickerson, B.P. 1976. Soil compaction after tree length skidding in northern Mississippi. Soil Sci. Soc. Am. J. 40: 965-966.

5. Dyrness, C.T. 1965. Soil surface conditions following tractor and high-lead logging in the Oregon Cascades. J. Forestry 63: 272-275.

6. Dyrness, C.T. 1967. Mass soil movements in the H.J. Andrews Experimental forest. U.S.F.S. Research Paper PNW-42. PNW For. and Range Exp. Sta., Portland. 12 pp.

7. Dyrness, C.T. 1970. Stabilization of newly constructed road backslopes by mulch and grass-legume treatments. USFS Research Paper PNW-123. PNW For. and Range Exp. Sta., Portland. 5 pp.

8. Fredricksen, R.L. 1965. Sediment after logging road construction in a small western Oregon watershed. USDA Misc. Publication 970, Paper #8. Washington, D.C. 4pp.

9. Froehlich, H.A. 1979. Soil compaction from logging equipment: Effects on growth of young ponderosa pine. J. of Soil and Water Conservation 34(6): 276-278.

10. Haupt, H.F. 1959. A method for controlling sediment from logging roads. USDA Forest Service Misc. Publ. No. 22. INT Forest and Range Exp. Sta., Ogden, Utah. 22 pp.

11. Lull, H.W. 1959. Soil compaction on forest and range land. Misc. Publ. No. 768. U.S. Dept. Agric., Washington, D.C. 64 pp.

12. McCammon, B.P. 1982. Fire rehabilitation in the Bend Municipal Watershed. Paper distributed at: WSU Soil Erosion and Sediment Control Short Course (March 23-24, 1982), Olympia, Wash. 6 pp.

13. Megahan, W.F. 1977. Reducing erosional impacts of roads. In: Guidelines for Watershed Management. FAO Conservation Guide. FAO of the U.N., Rome. pp. 237-261.

14. Megahan, W.F. 1981. Effects of silvicultural practices on erosion and sedimentation in the interior West--a case for sediment budgeting. In: Proc. Symp. on Interior West Watershed Management (April 8-10, 1980, Spokane, Wash.). WSU Co-operative Extension, Pullman, pp. 169-181.

15. Megahan, W.F., N.F. Day, and T.M. Bliss. 1978. Landslide occurrence in the western and central Northern Rocky Mountain physiographic province in Idaho. In: Fifth North American Forest Soils Conf. (Fort Collins, Colo., Aug. 1978). CSU, Fort Collins, Colorado. pp. 116-139.

16. Mitchell, W.K. 1982. The construction and rehabilitation of logging landings in the Cariboo Forest Region. Research Branch #20, B.C. Min. of Forests, Cariboo Forest Region. Williams lake, B.C. 30 pp.

17. Packer, P.E. 1967. Criteria for designing and locating roads to control sediment. For. Sci. 13(1): 2-18.

18. Reed, L.J. and M.M. Hektner. 1981. Evaluation of 1978 revegetation techniques. Redwood National Park Watershed Rehabilitation, Tech. Report 5. Arcata, Calif. 70 pp.

19. Reid, L.M. T. Dunne, and C.J. Cederholm. 1981. Application of sediment budget studies to the evaluation of logging road impact. J. of Hydrology 20(1): 49-62.

20. Rice, R.M., J.S. Rothacher, and W.F. Megahan. 1972. Erosional consequences timber harvesting--on appraisal. In: Proc. Symp. on Waterhsheds in Transition (Fort Collins, Colorado, June 19-21, 1972). Water Resources Association Series 14. pp. 321-329.

21. Sidle, R.C. 1980. Slope stability on forest land. USDA Forest Service Ext. Publ. PNW-209. PNW For. and Range Exp. Sta., Portland. 23 pp.

22. Smith, R.B. and E.F. Wass. 1979. Tree growth on and adjacent to contour skidroads in the subalpine zone, southeastern B.C. Environment Canada, Forest Service BC-R-2. Victoria, B.C. 26 pp.

23. Steinbrenner, E.C. 1955. The effect of tractor logging on physical properties of some forest soils in southwestern Washington. Soil Sci. Soc. Am. Proc. 19: 372-376.

24. Steinbrenner, E.C. and S.P. Cessel. 1955. Effect of tractor logging on soils and regeneration in the Douglas-fir region of southwestern Washington. Soc. Am. For. Proc. 1955: 77-80.

25. Youngberg, C.T. 1959. The influence of soil conditions, following tractor logging, on the growth of planted Douglas-fir seedlings. Soil Sci. Soc. Am. proc. 23: 76-78.

26. Wert, S. and B.R. Thomas. 1981. Effects of skidroads on diameter, height, and volume growth in Douglas-fir. Soil Sci. Soc. Am. J. 45: 629-632.

SOIL DEGRADATION BY MASS MOVEMENT IN BRITISH COLUMBIA

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INTRODUCTION

Mass movement is the downward movement of a mass of surficial materials or a detached mass of bedrock due to gravity. (By surficial materials I mean geologically young sediments, such as glacial till, gravel, sand and clay: the materials that an engineer would call "soil".) The mass of material that moves downslope may contain water or ice, but it is not actually transported by flowing water or ice. Thus mass movement includes such things as debris flows, landslides, and soil creep. In a strict sense, it also includes subsidence and collapse of the land surface into underground cavities, but in this paper I will be referring only to downslope mass movements unless otherwise specified.

The definition of mass movement that I have just given allows it to be distinguished clearly from "erosion". Erosion is the removal and transportation of materials by flowing water, ice, wind, or waves. Material generally is picked up particle by particle, not "en masse". The term "mass wasting" is commonly applied in a broad sense to the combined effects of weathering and mass movement and erosion.

Soil degradation -- or soil loss - due to mass movement takes place in several different ways. When rapid mass movement occurs, mature soil is lost and unweathered substrate is exposed instead. The displaced material comes to rest further downslope where it may bury mature soil and vegetation. Where mass movement occurs slowly but continuously, the land surface is deformed by pressure ridges and tension cracks, trees are tilted, and drainage is disrupted. Where landslides occur along the edges of terraces, flat land is replaced by chaotic and hummocky slide topography. Mass

movements near the head of a drainage basin may initiate erosion and loss of productive land along the river further downstream.

THE CAUSES OF MASS MOVEMENT

The basic causes of mass movement are illustrated in Figure 1. Any mass of bedrock or surficial material that is part of a slope is affected by a downslope gravitational force (shear stress) "G", and held in place by a frictional effect "F". The gravitational force is proportional to the weight (mg) of the potential slide material and the angle ($\sin \alpha$) of slope. Friction derives from the internal structure and cohesion (ie. the shear strength) of the material that constitutes the slope. If a structural discontinuity is present along which sliding may occur, then the frictional effect is related to the roughness of this surface.

Slope failure (sliding of the block in Figure 1) will occur when the gravitational force exceeds friction ($G > F$). Obviously this can be brought about either by an increase in G or a decrease in F.

Conditions that lead to a decrease in F are those that reduce the internal cohesion of the slope material or emphasize the discontinuity that is the potential slip plane. One of the most effective means of reducing cohesion is the development of high hydrostatic pressure in the water occupying pores (high pore pressure) or other cavities (Fig. 2). This can occur as a result of prolonged rainfall, seepage of groundwater from upslope, and mismanagement of water from roads, storm sewers and irrigation. Cohesion of slope materials may also be reduced by weathering (for example, leaching of calcium carbonate), by decay of a root network, and by mechanical loosening due to root growth, soil fauna, and freeze-thaw of moisture at shallow depths.

Potential slip planes are bedding planes, joints, beds of weak rock, and the contacts between surficial materials and bedrock, between weathered and unweathered till, and between two different

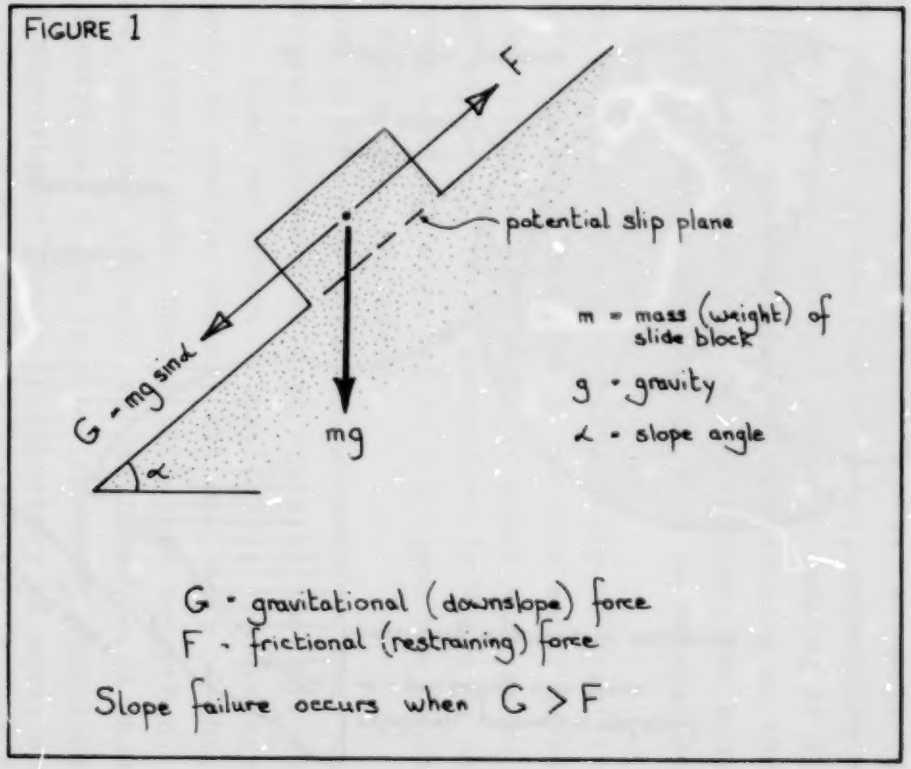

Figure 1. Simple model to illustrate basic causes of mass movement.

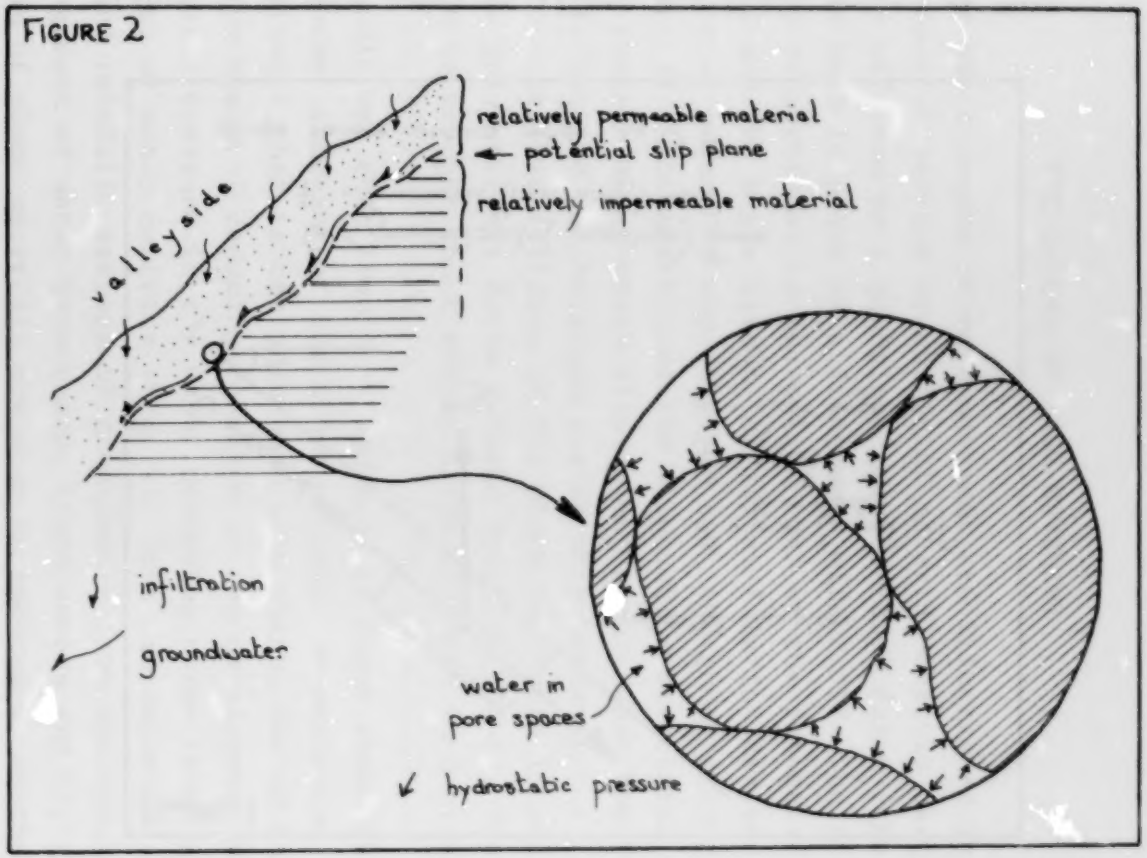

Figure 2. Development of high pore water pressure and potential slip plane on typical valleyside. Relatively permeable material may be weathered till or colluvium; relatively impermeable material may be unweathered till or bedrock.

kinds of surficial material. Movement of groundwater and accumulation of organic matter along contacts in surficial materials act to reduce cohesion and increase the likelihood of sliding.

Conditions that lead to an increase in the gravitational force, G, are those that either increase the weight of the potential slide block or increase the steepness of the slope. Weight can be added due to growth of biomass, accumulation of a thick and wet snow cover, addition of water, deposition of material from further upslope (eg. rockfall debris), dumping of fill, and construction. Slopes are steepened by undercutting at the base due to river erosion, wave erosion along shorelines, and benching for construction sites, and by addition of fill or natural accumulations to the upper slope.

On slopes that are in a precarious state of stability, that is, where G is only slightly less that F (or even equal to F), mass movement may be triggered by a specific event such as an earthquake, an explosion, or an exceptionally heavy rainstorm. Extremely strong wind may also act as a trigger due to the stress it exerts on a slope via the trees.

Soil creep is the slow downslope movement of soil and surficial material. Movement is most rapid at the soil surface, (typically 1 to 12mm per annum; Young, 1972), and decreases downward to zero at shallow depths. The mechanics of this process do not fit the general model that I have just described. Creep occurs because, whenever the soil is disturbed, even though particles move in all directions, there is a net movement downslope due to gravity. Soil disturbance occurs in a variety of ways, such as by growth of roots and the burrowing activities of soil fauna. But processes that involve heaving and settling (ie. expansion and contraction of soil volume) are probably most effective. These are wetting and drying, and particularly, the growth and melting of needle ice (Fig. 3).

Subsidence and collapse of the ground surface are caused by the formation and growth of underground cavities until the roof structure is so weak that it collapses or settles down. Collapse depressions are found in areas of soluble bedrock, particularly

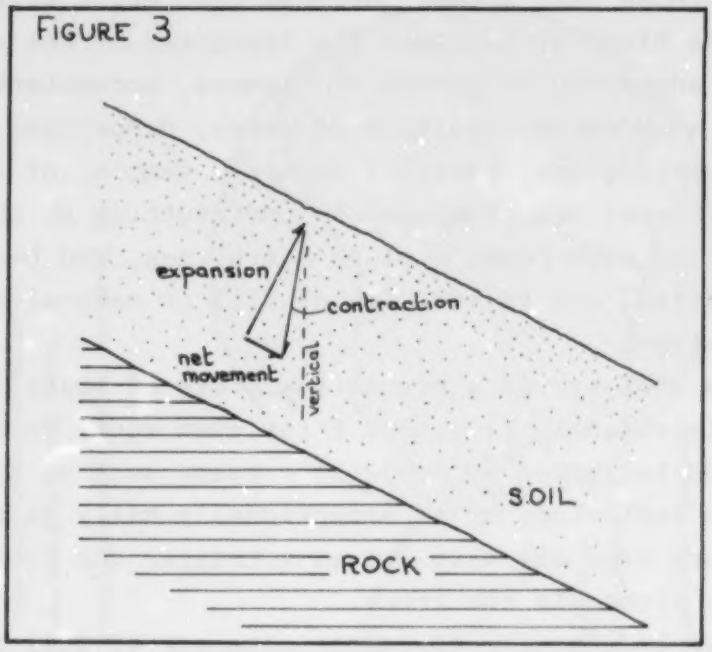

Figure 3. The heave mechanism in soil creep (from Young, 1970).

limestone and gypsum, and in areas where subsurface conduits are formed by the washing away of particulate material, a process known as "piping". Piping is widespread in the glacio-lacustrine silts of the South Thompson and Okanagan Valleys.

THE EFFECTS OF MASS MOVEMENT

Types of Mass Movement

Material that breaks from a slope and travels downhill does so in a variety of ways and produces many different kinds of landforms and deposits, (cf. Sharpe, 1938; Varnes, 1978; Swanston, 1974). Mass movement processes are distinguished from each other on the basis of characteristics such as:

- rate of movement: which ranges from imperceptible (requiring repeated accurate measurements for recognition) to rapid (several metres per second);
- moisture content: which varies from dry to saturated (water), or a high proportion of snow;
- source material: which may be bedrock, or surficial material, or snow (snow and ice avalanches are forms of mass movement);
- type of movement: whether sliding, flowing, or falling (Fig.4);
- cohesiveness of the moving material: whether it remains as one or a few coherent pieces or whether it shatters into fragments.

The most commonly occurring processes of mass movement in British Columbia and their most important characteristics are shown in Table 1. Typical landforms that result from these processes are illustrated in Varnes (1978), Eisbacher (1979), and Howes (1981).

In general, a site where slope failure occurred (ie. the actual place of rupture) is marked by a "slide scar". This landform is most typically a steep, concave slope that is arcuate in plan, but it ranges from deep, horseshoe-shaped embayments in the case of some earthflows, to fresh unweathered patches on a cliff from which some rock has recently detached and fallen.

Material that is deposited on or at the foot of slopes due to mass movement is known as "colluvium". Many mass movement

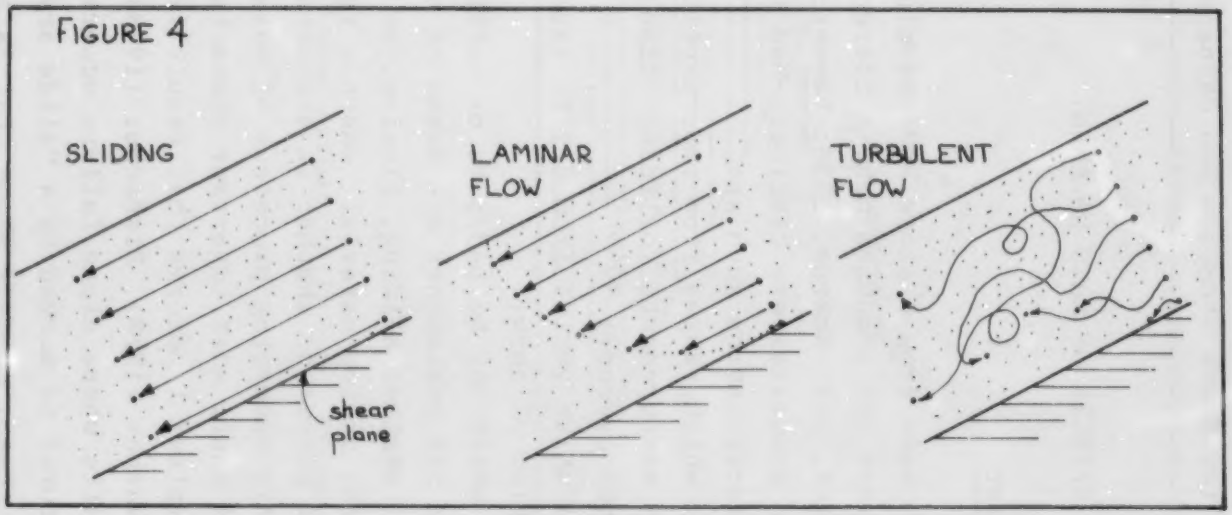

Figure 4. Types of movement.

Table 1. Common mass movement processes in British Columbia

Type of movement	Type of material: Bedrock	Type of material: Unconsolidated	Other characteristics
Falling	ROCKFALL	DRY RAVEL (gravel)	v. rapid and dry
		DEBRIS FALL (other)	
Sliding	ROCK SLUMP	SLUMP	cohesion retained; imperceptible to very rapid
	ROCKSLIDE	DEBRIS SLIDE	disintegrates; usually very rapid
Flow	EARTHFLOW (weathered bedrock)	EARTHFLOW	increasing water content ↓ imperceptible
		DEBRIS FLOW	rapid
		DEBRIS TORRENT*	very rapid
Creep		SOIL CREEP	imperceptible; moisture content (water and ice) varies
Complex	some large landslides**	SOLIFLUCTION	imperceptible; moist (water and ice)
	SLUMP-EARTHFLOW	SLUMP-EARTHFLOW	imperceptible to rapid; moist

* The moisture content of debris torrents is so great that flowing water is actually an agent of transportation. However, a complete gradation exists between debris torrents, flows, and slides, and so debris torrents are listed here for the sake of completeness.

** The term "landslide" is used to refer to large and complex mass movements, and also as a popular name for large slumps, slides and earthflows.

processes, for example rockslides, earthflows, and large complex landslides, result in irregular, hummocky and ridged mounds of colluvium. Processes which are recurrent at certain sites, such as debris flows, rockfalls, and snow avalanches (which contain rock debris), construct cones and fans of colluvium. Creep processes and solifluction give rise to extensive mantles of slowly moving debris on slopes and wedge-shaped accumulations of colluvium at their toes.

Some forms of rapid mass movement, for example debris flows and snow avalanches, leave distinctive "tracks" which connect their source areas with their depositional zones. Tracks may simply be routeways that have been swept clear of vegetation and soil, or they may be marked by small accumulations of colluvium. Debris flow tracks are commonly bordered by ridges of muddy debris ("debris flow levées) that become stranded along the relatively dry margins of the flow.

Long-Term Effects of Mass Movement

Mass movement processes have been modifying the British Columbia landscape for about 12 000 years since the end of the last glaciation (Fraser Glaciation). Erosion by valley glaciers in mountainous terrain had produced steep slopes in bedrock, such as the sides of U-shaped valleys (Fig. 5) and cirque headwalls. When these slopes were exposed by ice recession, they were immediately vulnerable to the effects of weathering and mass movement. Rockfalls, rockslides and similar processes have continued throughout postglacial time. In general, they have resulted in a decrease in the gradient of bedrock slopes, a reduction of the extent of exposed bedrock on slopes, and the formation of extensive deposits of colluvium and accumulations of weathered rock debris (Fig. 5).

The effectiveness of weathering and mass movement processes is partially dependent upon the type of bedrock that is involved. For example, valleyside gradients are, on average, more gentle and debris covered areas (colluvium and weathered bedrock) are

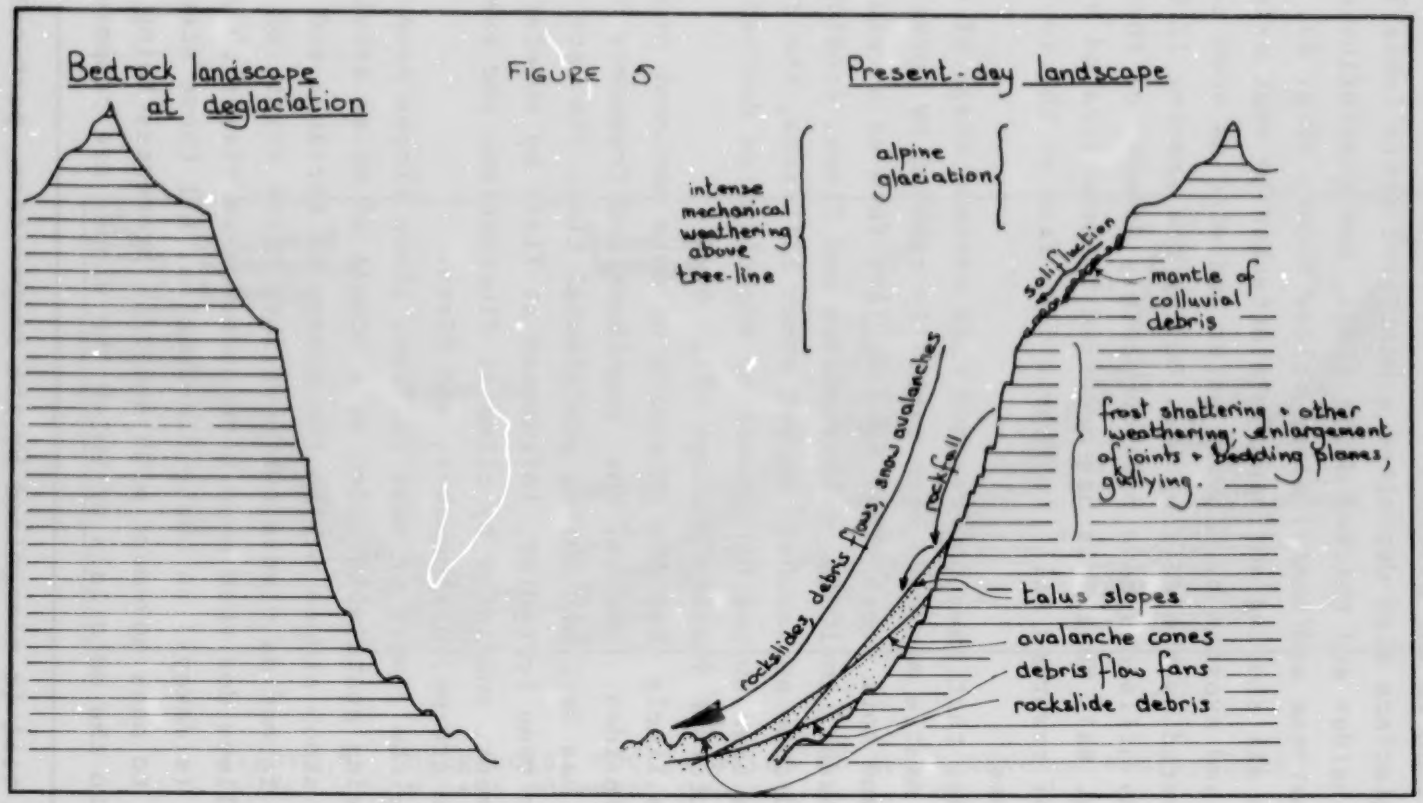

Figure 5. Postglacial modification of bedrock landscape by mass movement processes.

more extensive on the sedimentary rock formations of the Rocky Mountains than on the plutonic rocks of the Coast Mountains.

The glaciers also deposited a mantle of drift (chiefly till) on mountainsides and thicker drift (till, and glaciofluvial and glaciolacustrine sediments) along valley floors (Fig. 6). Drift mantles on all sloping surfaces were attacked by weathering, mass movement, and erosion by flowing water and wind as soon as they were uncovered by the melting ice. During the ensuing 12 000 years, many hillsides have been completely denuded of their drift cover (Fig. 6a). That this has occurred is demonstrated by the presence of reworked till* in debris flow fans at the foot of rocky slopes.

On hillsides that have not reached this extreme stage of denudation, the drift mantle may have been partially removed by localized gullying and soil creep (Fig. 6b). Gullies form as a result of many processes, including debris slides and flows, erosion by running water, and snow avalanches. On yet other hillsides, the drift mantle has been buried by a covering of colluvium derived from bedrock outcrops further upslope (Fig. 6c).

It is likely that the intensity of mass movement processes on mountainsides, that is, the magnitude and frequency of slope failures, has declined during postglacial time. The rate of decline would have been irregular, influenced at first by vegetation establishment, and later by climatic fluctuations and events such as intense storms, earthquakes, and fires.

Along the floors of most valleys, steep slopes have been formed during postglacial time as a result of river erosion (Fig. 7). These steep slopes may be the scarps of terraces and benches that were formed as rivers cut down into thick drift, or they may be valleysides that have been undercut as rivers shifted laterally (sideways) on their floodplains. All these steep slopes are prone to mass movement with specific processes being related to the materials of which the slopes are composed. For

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*Reworked till is recognized by its composition, particularly the presence of rock fragments from distant sources.

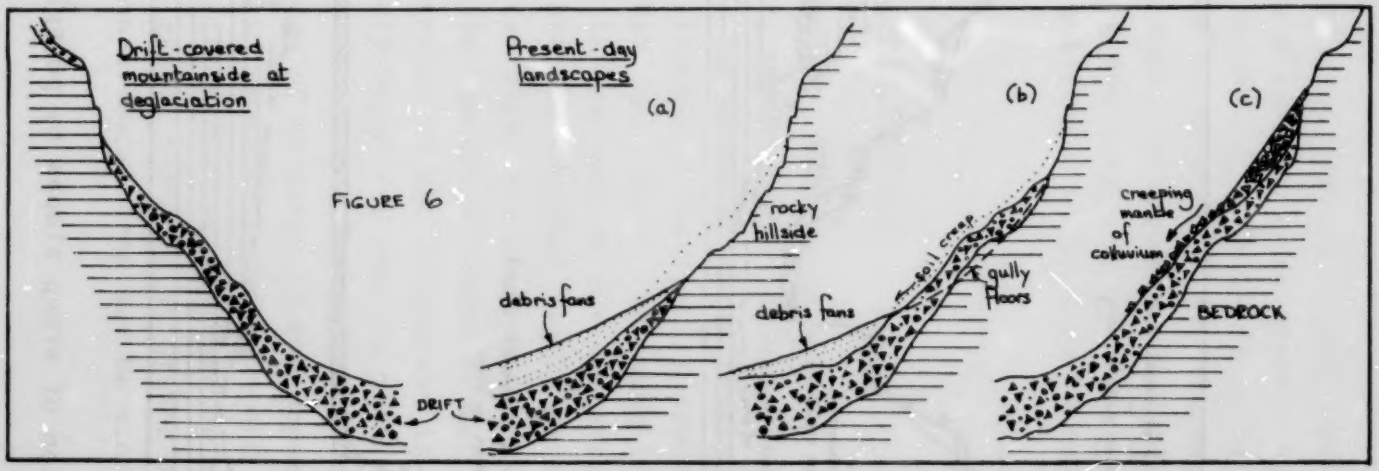


Figure 6. Postglacial modification of drift-covered valleysides by mass movement processes.

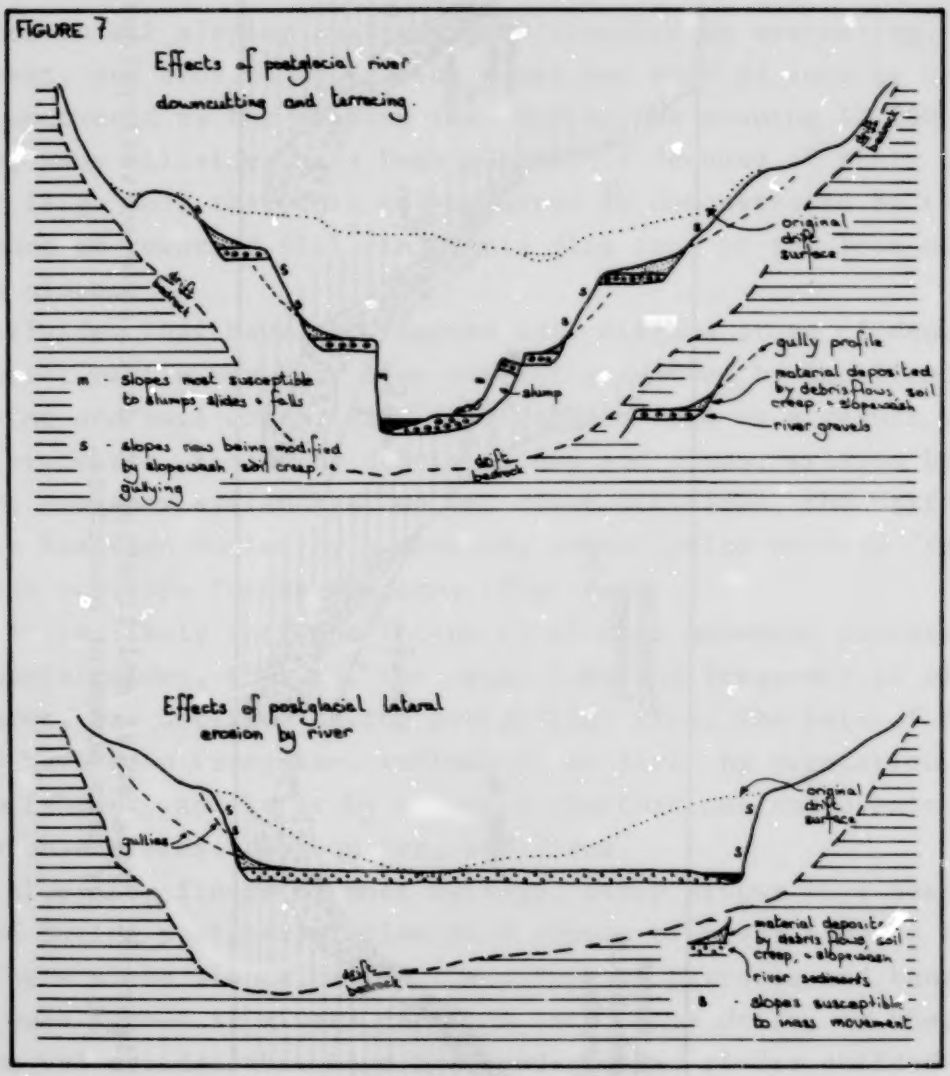


Figure 7. Formation of steep slopes by postglacial river erosion.

example, scarp slopes cut in glaciolacustrine silts are susceptible to slumps and earthflows; the gradients of scarps cut in gravels are gradually reduced by dry ravel (falling particles), shallow slides in loose gravel, and soil creep.

Scarps that are presently being undercut by rivers are the steepest and most prone to failure. Older scarps, those that have not been trimmed by a river for hundreds or thousands of years, are more gently sloping and likely to be affected only by soil creep, slopewash and gullying, rather than by deep-seated slope failures.

Downstream Effects of Mass Movement

Mass movement supplies sediment to streams and rivers. In steep mountain valleys, material from debris slides and other slope processes may be deposited either directly into the stream channel, or onto the floodplain where it is eroded and reworked by the stream at some later date. Since the capability of any river to transport sediment is governed by its discharge and channel gradient, it is possible for sediment supply to exceed the river's transporting capability. When this happens, sediment is only redistributed locally by the river, there is net accumulation of sediment, and the elevation of the floodplain is increased. The river becomes relatively broad and shallow with numerous gravel bars, and its tendancy to shift sideways and erode its banks is increased. Thus addition of material to the upper part of a creek from mass movement, may result in increased bank erosion downstream and replacement of a stable low terrace, bearing mature soil and vegetation, by a broad gravel floodplain. Gravel deposition and shifting stream beds on alluvial fans may be similarly induced.

ASSESSMENT OF THE PROBLEM

The "problem" of mass movement can be addressed from several perspectives. First, it is important to bear in mind that mass movement is a natural and normal process. It is not unusual nor solely the result of bad land management. Thus it differs from effects such as acidification and compaction that have been described earlier. So we must plan to live with a certain amount of mass movement.

There are two ways in which mass movement can pose problems. The intensity (magnitude and frequency) of slope processes may be increased as a result of certain land use practices, thus giving rise to "accelerated mass movement". Also, natural mass movement is so widespread in our mountainous and steep terrain, that it commonly represents a hazard or a constraint to land use. We can, and should, take account of this latter condition by carrying out terrain surveys in order to locate active slopes, and then planning to avoid hazardous sites; engineering studies are necessary for detailed planning. The former problem is much more difficult to assess.

Accelerated Mass Movement

The obvious effects of accelerated mass movement, such as soil loss and site degradation, are well known. The real problems here, however, are to distinguish between the long term rates of normal and accelerated mass movement, and to ascertain whether or not the long term effects of accelerated mass movement are significantly different from those of normal mass movement.

In order to illustrate these points, I have constructed the two artificial graphs that are shown in Figure 8. Graph (a) shows natural mass movements. Note that rates are so variable that a long term record would be required to estimate even an average condition. Graph (b) shows mass movement accelerated by some kind

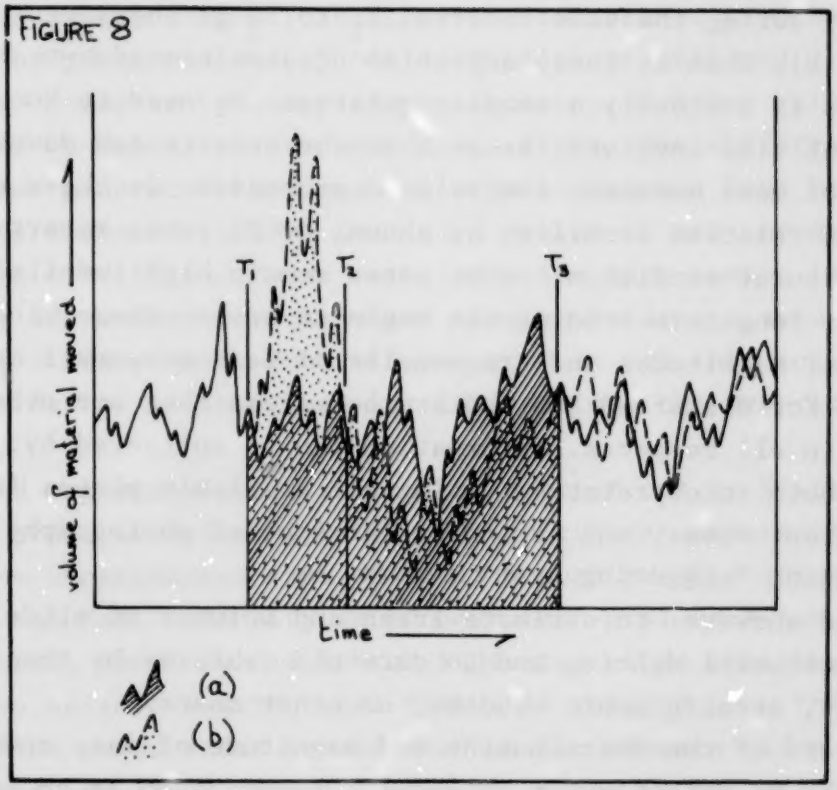


Figure 8. Hypothetical graphs of natural mass movement (a), and mass movement modified by slope disturbance (b).

of disturbance to slope conditions that occurred at time T_1. Graph (b) also shows a period of relative slope stability after time T_2, which possibly occurs because so much unstable material sloughed away during the time interval between T_1 and T_2. Slopes remain in this state of reduced activity until continued weathering and other processes again make material available for mass movement, and then rates increase to "normal" at T_3. If the volume of material that was moved downslope, or soil loss that occurred, during the time interval T_1 to T_3 is the same in both (a) and (b), then is there a problem of accelerated mass movement?

This is obviously a complex question. We need to know the lengths of time involved, as well as the on-site and downstream effects of mass movement and related processes. Is there a period of relative stability as shown, or do rates revert back to the natural condition, or do rates remain high indefinitely?

Only long-term studies can begin to answer these kinds of questions. Magnitudes and frequencies of mass movements must be assessed for disturbed and undisturbed areas that are otherwise similar in all respects. Information can be collected by:

- air photo interpretation: using all available photos from different dates, and arranging for special photography if an important triggering event occurs:
- ground surveys: to estimate areas and volumes of slide scars and colluvial debris, and to date old features by tree-ring counts, stratigraphic studies, or other means;
- analysis of the distribution and magnitude of mass movements induced by a particular triggering event, such as an earthquake or an exceptionally severe rainstorm.

The Extent of Mass Movement in British Columbia

Although as far as I am aware, no single map exists that shows the distribution of mapped mass movement features in British Columbia, mass movement landforms and colluvium have been mapped at larger scales (1:50 000, 1:250 000) for many parts of the

province. These features are shown on terrain maps, surficial geology maps, and some bedrock maps, and can be recognized on some soils maps. The various government agencies that produce and distribute these maps are listed at the end of this paper.

As a result of these mapping programmes, some generalizations can be made about the distribution and extent of mass movement features (cf. Howes, 1981). The surficial materials most commonly involved in deep-seated failures (slumps, earthflows, some slides) are clays and silts of glaciolacustrine, lacustrine, glaciomarine, and marine origins, and clayey tills. Mantles of till and colluvium on moderate to steep slopes in areas of heavy rainfall are affected by debris slides and debris flows. The different kinds of landslides generated by slope failures in bedrock have been described by Eisbacher (1979) in a good review of mass movement in the Canadian cordillera. Major rockslides are most common in sedimentary and volcanic rocks where sloping bedding planes function as slide planes. Rock slumps occur in volcanic rocks along the steep sides of valleys that are incised into the interior plateau.

A broad regional analysis was also carried out by Eisbacher (1979). In order to define likely areas of highest natural landslide activity, he superimposed maps of total annual precipitation (a measure of rainfall intensity would have been preferred but was not available), local relief (which indicates slope steepness), and relative seismic (earthquake) risk. His results show that the most landslide prone areas are located on the western sides of the Coast and Insular Mountains where all three causal effects are high, and in the northern Selkirk Mountains and in the Rocky Mountains between Yellowhead Pass and McGregor River where relief and precipitation are high. Geological materials are not included in this analysis, but nevertheless, it gives a good overview of the general intensity of slope processes.

PREVENTION AND CURE

Remedial measures -- procedures that may halt slope movement once it has started -- should be considered only as a last resort. Prevention or avoidance of mass movement is far more effective and less costly than most cures.

In order to avoid initiating or accelerating mass movement on a slope where some kind of disturbance of natural conditions is planned, "sensitive sites" should first be identified. These may be particularly steep segments of a mountainside, or slopes where rapid soil creep is occurring, or terrace scarps underlain by glaciolacustrine silts, or slopes already affected by debris slides under natural conditions. Sensitive sites can be identified by terrain and soil surveys, provided that the scale of mapping is such that it shows the variability of terrain and soil conditions across the area in question. The method of identification that is employed should also lead to recognition of the critical condition(s) that is controlling slope stability at the sensitive sites, for example, excess moisture, slope steepness, potential slide plane. Then land use procedures can be selected that will minimize disturbance of that condition. Avoidance of <u>any</u> site disturbance should also be an option. If construction is planned, or if potential slope failure threatens valuable property or occupied buildings, then a detailed engineering investigation (drilling and laboratory tests of soil strength for example) should be undertaken.

Methods that can be adopted to stabilize slopes where mass movement is occurring or is imminent vary widely depending upon specific site conditions, but generally involve either drainage or removal of water source, and establishment of vegetation. Retaining walls, buttresses, and bolts are commonly used to provide support for unstable cutbanks along highways and railroads, but it obviously is impractical to apply these measures over extensive areas. Some slow-moving rotational slumps have been halted by applying weight to their toes.

CONCLUSIONS

In conclusion, it is suggested that plans for any kind of land use in mountainous or steep terrain should recognize that a certain amount of natural soil loss will occur due to mass movement. This can be only slightly and temporarily offset by remedial measures. Accelerated mass movement can be avoided if sensitive sites are identified prior to slope disturbance and treated suitably. This should be done at least until the significance of accelerated mass movement is more fully understood.

REFERENCES

Eisbacher, G. H. 1979. First-order regionalization of landslide characteristics in the Canadian cordillera. Geoscience Canada, 6, 69-79.

Howes, D. E. 1981. Terrain Inventory and Geological Hazards: Northern Vancouver Island. Assessment and Planning Division Bulletin 5, British Columbia Ministry of Environment, 105pps.

Sharpe, C. F. S. 1938. Landslides and Related Phenomena: A Study of Mass Movements in Soil and Rock. Columbia University Press, New York, 137pps.

Swanston, D. N. 1974. Slope Stability Problems Associated with Timber Harvesting in Mountainous Regions of the Western United States. United States Department of Agriculture, Forest Service, General Technical Report PNW - 21, 14pps.

Varnes, D. J. 1978. Slope movement types and processes. Chapter 2, 12 - 33, in Landslides Analysis and Control. Editors Schuster, R. L. and R. J. Krizek. Special Report 176, Transportation Research Board, National Academy of Sciences, Washington, D. C.

Young, A. 1972. Slopes. Oliver and Boyd Publishers, Edinburgh. 288pps.

MAP SOURCES

Terrain maps and soil maps are available from:

Map Library, Resource Surveys and Mapping Branch (formerly Terrestrial Studies Branch and Resource Analysis Branch), Assessment and Planning Division, British Columbia Ministry of Environment, Parliament Buildings, Victoria, V8V 1X5.

Research Branch, Agriculture Canada Research Station, 6660 N.W. Marine Drive, Vancouver, V6T 1X2.

Sales and Publications, Geological Survey of Canada, 100 West Pender Street, Vancouver, V6B 1R8.

TOWARDS SOIL CONSERVATION IN B.C.

R.A. Bertrand, P. Ag.
B.C. Ministry of Agriculture and Food

1.0 INTRODUCTION

Soil is the basic resource upon which both agriculture and forestry depend. Loss of the productive capacity of the soil due to the various degradation processes described by previous speakers, may eventually render the soil unable to support a sufficient level of plant growth. Since many farmers depend on the productivity of the soil for their long term economic survival, the necessity for the adoption of soil conservation management practices would seem to be obvious.

Where soil degradation is markedly affecting productivity and the methods for alleviation are relatively simple and inexpensive, education and extension will usually result in the land user adopting appropriate management practices. However, soil degradation is often a gradual process and the effects on productivity are not apparent from one year to the next. In the short term, soil conservation measures are usually not cost effective for individual farmers. For example, in a study of land in southern Iowa it was found that to reduce soil erosion to a tolerable level would cost farmers three times as much as the immediate economic benefits.

An even more serious impediment to the adoption of soil conservation management practices is that in many instances, the use of management practices that accelerate soil degradation, maximize short term economic returns. Such practices include large fields which are susceptible to wind erosion, but minimize turning and allow the use of large equipment; removal of shelter belts, grassed waterways, and permanent cover from sloping land which increases cultivated acreage; and long term mono cultures are often more profitable than crop rotations.

To observe the benefits of soil conservation, the long term view is required. What will be the consequence of 50 or 100 years of current soil management practices? Few farmers can afford to

to be concerned about the productivity of their land 100 years from today. Since maintenance of the long-term productivity of our soils is a legitimate concern of the people of B.C., the government needs to join with farmers and the farm community to institute policies and programs of soil conservation.

This paper briefly discusses some of the most recent publications on the extent of soil degradation in Canada, reviews the experience in the U.S. with soil conservation legislation, evaluates past and current B.C. legislation in this area, and provides some suggestions on possible routes "towards soil conservation" in B.C.

2.0 RECENT DOCUMENTS ON SOIL DEGRADATION

2.1 Soil Conservation Policy - Canadian Federation of Agriculture, August 1982

This paper was prepared as a background document for a Soil Conservation Workshop held in Ottawa in December, 1982. It is interesting to note that this workshop was initiated by the Canadian Federation of Agriculture, the national organization of farmers, and soil scientists from across Canada were invited. However, no representatives from the B.C. government service were allowed to attend.

The C.F.A. Standing Policy calls for "the use of soil, water, and other natural resources in conformity with good conservation practices." However, the C.F.A. is concerned that "what Canadian farmers are doing may not, in the long term, be in concert with this policy."

After a general discussion of soil degradation in Canada, the paper makes some relevant observations and poses some difficult questions. A few of these are as follows:

a) "As farmers we seem to be willing to sacrifice long term production potential for the sake of short term profit: and this runs counter to the call of C.F.A. Standing Policy."

b) "For those who use the land, if they do not manage the soil for long term production, we may, in the next century, be facing catastrophe."

c) "Is the farmer who owns his land responsible for conserving it in good heart? Should the country at large have a say in the matter? Does the farmer have a right to ignore good conservation practices? Who pays?"

d) "Conservative farming does not generally appear attractive from the point of view of maximizing short term profit, judged on the basis that many people do not practice it."

e) "Government measures appear to fall short of recognizing soil degradation as a priority issue."

Following are some of the conclusions drawn by the C.F.A.:

a) "There is a need to conserve and maintain the limited capacity of the Canadian soil resource for permanent food production."

b) "We need to review the means of extending soil conservation advice and technology to farmers."

c) "If there is a cost to farmer revenue in conservative farming, we need to agree on who shoulders the responsibility, and who pays."

d) "We need coordination of government (and conservation authorities, etc.) on a common policy with respect to soil conservation and uniformity of application by different government departments."

e) "Rehabilitation programs, with strong government support, are needed where erosion, salinization, compaction and other processes of degradation have gone beyond individual farmer control."

2.2 Land Degradation and Soil Conservation Issues On the Canadian Prairies - An Overview; Prairie Farm Rehabilitation Administration, November, 1982

This report highlights the extent and nature of soil degradation issues which threaten the future productivity of the Prairie agricultural land base. It also outlines

the implications of soil degradation for the national economy. Much of the material is directly applicable to the Peace River region of B.C. and is relevent with regard to the general issue of soil conservation in B.C.

After reviewing the current activities of various government agencies, PFRA concludes that "Almost four decades have passed since any form of concerted effort towards soil conservation has existed in Canada. Clearly a situation exists where an effective response to emerging soil degradation problems by both federal and provincial governments must be considered essential."

2.3 An Assessment of the Degradation of Agricultural Lands in Canada; Coote, Dumanski, Ramsey. 1981

The monograph presents a general qualitative assessment of the kind, location, and extent of land degradation in the agricultural regions of Canada. In the Summary and Conclusion section it is stated that:

"A situation must be reached where scientists, specialists, extension workers, the farming community and the public at large are made aware of the present and potential problems as well as the alternatives for their control. The eventual aim must be a state of land stewardship that maintains the land resource in an optional or best possible state for agricultural production relative to the regional climate of the area. The alternative is short-term economic gain, but a long-term, non-redeemable mortgage on the future."

2.4 America's Soil and Water: Conditions and Trends; U.S.D.A., December, 1980

This document is a summary of some of the findings of the National Resource Inventories begun by the Soil Conservation Service in 1977. It was found that enhanced conservation treatment is needed on 58% of the U.S. cropland, 75% of the pasture and rangeland, and on 67% of the forest land.

These figures apply to a country where 2 million land users work through local conservation districts to apply practical systems of soil conservation on their farms and ranches. In addition, technical assistance is available from the USDA's Soil Conservation Service and cost sharing from SCS and the Agricultural Stabilization and Conservation Service.

The unavoidable conclusion from reviewing these documents and listening to the previous speakers is that we have a problem in B.C. and Canada and there isn't much being done about it. In fact, current government programs and policies combined with prevalent land management practices are accelerating the problem. Even in the U.S. where coordinated action on soil conservation issues has been much greater than in Canada, soil degradation is an on-going, serious problem.

3.0 THE U.S. EXPERIENCE: SOIL CONSERVATION DISTRICTS

3.1 Introduction

In 1929 funds were allocated to conduct investigations of soil erosion which had been identified as a "menace to the economy, health, and general welfare of the United States." From that starting point the soil and water conservation movement has expanded to the point where there are over 3000 soil conservation districts and over 2 million land owners have been directly assisted.

3.2 Soil Conservation Districts Law

In 1937 a standard state soil conservation districts law was sent from the President to all states which suggested that authority be given to farmers and ranchers to organize districts specifically for conservation of soil and water. The standard law has three basic considerations:

a) A genuine attack on soil erosion requires considerable modification of land-use practices.

b) Virtually all lands in eroding water sheds must be brought under some form of erosion control for the problem to be alleviated.

c) Modification of land-use practices and erosion prevention can be made effective only if farmers cooperate voluntarily.

3.3 Soil Conservation Districts

Districts are governmental sub-divisions of the State and exercise two main types of powers:

a) establish and administer erosion control demonstration projects

b) prescribe land-use regulations in the interest of erosion control with such regulations having the force of law

In the State of Washington there is a conservation districts law. The following are some pertinent items contained in this law and the standard soil conservation districts law.

3.3.1. Creation of Soil Conservation Districts

Any 25 occupiers of land lying within the area to be affected may file a petition asking that the area be organized into a district. Within 30 days the State Conservation Commission shall give notice of a public hearing. If, after the hearing, the Commission finds that the district is needed, the question is placed before the land owners in the form of a referendum. An affirmative response will usually result in the formation of the Soil Conservation District. The district is governed by 5 supervisors, 2 appointed by the state and 3 elected by the land owners.

3.3.2. Powers of Districts and Supervisors

The powers are very broad relative to land and water resources within the district. Some of these

include:

- to conduct surveys, investigations, and research
- to conduct demonstration projects
- to carry out preventive and control measures
- to make available equipment, fertilizer, seed, etc. for erosion control
- to construct, improve, and maintain erosion control structures
- to develop comprehensive plans for conservation in the district

3.3.3 Adoption of Land-Use Regulations

The Washington Law does not provide districts with the power to regulate land use. However, the standard law written by the federal government does envision the need to adopt land use regulations. The process for adoption includes the formulation of regulations by supervisors, presenting regulations at public hearings, and conducting a referendum.

Regulations may include provisions requiring:

a) the carrying out of necessary engineering operations
b) observance of particular methods of cultivation
c) particular cropping programs and tillage practices
d) retirement from cultivation of highly erosive areas

Enforcement of the land-use regulations is by a system of fines. If a land owner fails to conform to the regulations, the court may order compliance. If compliance is not forthcoming, the supervisors may cause the work to be done and recover costs from the land owner.

3.3.4 Summary

In the U.S. it is recognized that soil conservation is a conundrum or a Catch-22. "Farmers are not in the position to successfully combat soil erosion on their own, however, soil conservation will only be adopted

and made to succeed if initiated by farmers." Thus the government must actively support soil conservation by creating an awareness and then providing technical and financial support to help farmers adopt soil conservation management practices.

4.0 TOWARDS CONSERVATION IN B.C.

The previous sections of this paper have shown that many agencies, ranging from farmer organization to agricultural research groups, recognize soil degradation as a serious problem at the present time, and a potentially catastrophic problem in the future. And both government agencies and land users are doing little to alleviate the situation. In fact, current practices are exacerbating the problem in many cases.

The U.S. has nearly 50 years experience with coordinated programs of soil and water conservation. The system clearly works. Successes are not universal and much remains to be done. However, their system, whereby soil conservation programs are initiate and administered by the landowners themselves, should form the basis for any new initiatives in B.C.

4.1. Current and Passed B.C. Legislation

There are, or have been, legislative initiatives which recognize the need to preserve and maintain land in a productive state.

4.1.1. Soil Conservation Act (1956)

This act was repealed in 1977 and replaced with a new Soil Conservation Act which deals solely with the regulation of top soil removal from and placement of fill on lands within the A.L.R. The 1956 Act recognized that "debilitation" of lands should be prevented and established a mechanism whereby the Minister of Agriculture could authorize the investigations of problems, recommend corrective measures, and make regulations to prevent soil

erosion and soil debilitation. However, it is my understanding that no actions were ever undertaken pursuant to the act.

4.1.2. Agricultural Land Commission Act

This pioneering piece of legislation recognizes that a viable agricultural industry depends on a productive soils resource. Alienation of agricultural land can not proceed indefinitely without a serious negative impact on the agricultural industry and the province in general. It is in the public interest to preserve, where possible, agricultural land for agriculture.

However, once preserved, the land can still be managed (or mismanaged) in a manner that will reduce its capacity to support plant life. That is, a land owner is prevented from building a shopping center on agricultural land, but he can plant strawberries up and down a 10% slope and allow the topsoil to end up in the Fraser River. The long term result of both actions is land that can not support agricultural crops.

4.1.3. Environmental Management Act

This relatively new act does state that soil conservation is important for maintenance of a healthy environment. However, it in no way addresses the practical concerns relative to changing on farm management practices to prevent soil degradation.

4.1.4. Municipal Act

This act allows the Minister of Municipal Affairs to form Improvement Districts which join land owners together to deal with common problems. On the surface, this appears to parallel the

Conservation Districts in the U.S. However, it has been made clear to us in our contact with Municipal Affairs and officials of municipalities where erosion is occurring that there is no interest in using the improvement districts mechanism for dealing with soil degradation.

4.2 Proposals for B.C.

4.2.1. Soil Conservation Districts Legislation

The entire issue of soil degradation and its prevention can not be dealt with in a truly meaningful way without a legislative framework and a commitment from the political level. The U.S. experience has shown that all levels of government must join together to assist individual land owners to solve the problem of soil degradation. Soil and water conservation must be defined in provincial legislation as being in the public interest, but successful programs begin with, and are led by, people in their own communities in cooperation with their neighbors.

Soil Conservation legislation which uses the police powers of central government to impose soil conservation measures is generally ineffective and is very rarely used. Some reasons are as follows:

- there is often natural resentment by farmers towards governments and government officials telling them how to farm
- it does not tap the land ethic or feeling for the land which is deeply held by most farmers
- it often does not allow farmers to solve their own problems in their own ways
- there is a reluctance by political and government people to use the police powers of government to change farming practices

- it is almost always reacting to a problem after it has become serious rather than trying to prevent the problem from occurring

Thus, Soil Conservation legislation may have little impact upon soil degradation. The right type of legislation is required.

4.2.2. Extension and Education

Many soil degradation problems can be addressed by extension and education. I do not want to leave the impression that suitable legislation is required before anything can be done. Continued and enhanced activities in this area are required.

4.2.3. Research

Conservation measures may not be adopted because land owners are not aware that the problem exists or of the measures required to deal with the problem. Research is required to identify the extent and types of soil degradation and to develop appropriate techniques for alleviating the problem.

4.2.4. Funding

Who pays for soil conservation? The entire burden simply can not be shouldered by farmers. Any concerted effort towards soil conservation which depends solely on farmers for financial support is doomed to failure. If it is in the public interest to conserve the productive capacity of our soils, then it is incumbent upon the public to provide financial support.

a) A.R.D.A.

The Agricultural and Rural Development (B.C.) Act specifically allows B.C. to enter into agreements with the federal government for funding of soil

and water conservation projects.

The current Agricultural and Rural Development Subsidiary Agreement concludes in 1983. The B.C. Ministry of Agriculture and Food is seeking suggestions for items to be included in a proposal for a new agreement. One of the recommendations from this workshop will, hopefully be, that soil and water conservation be part of a new A.R.D.S.A. agreement.

b) A.L.D.A.

Under the Agricultural Land Development Act, farmers can obtain low interest loans for land development such as land clearing, irrigation, and drainage. Prevention and alleviation of soil degradation should also qualify as land development and be eligible for assistance. Demand for funds usually exceeds the quantities available. An increased level of funding and a broadening of eligibility could be a recommendation from this workshop.

c) Other Financial Programs

The B.C. public currently provides financial support to farmers and ranchers through programs such as Farm Income Insurance, Crop Insurance, and Interest Reimbursement. Should these funds be provided to farmers who fail to adopt conservation management practices? Where soil degradation has been identified as a problem, funding should be withheld from farmers who do not take steps to deal with soil degradation.

d) Incentives

In many jurisdictions, funds are available to individual farmers to encourage them to make changes which will improve soil management. Under

the Ontario Farm Productivity Incentive Program, funding is provided for grassed waterways, catch basins, tile outlet protection, reclaimation of gulleys, construction of contours, etc. Such a program should be considered for B.C.

WORKSHOP OF FEBRUARY 18, 1983

DISCUSSION LEADERS' SUMMARIES

GROUP 1: SOIL DEGRADATION EFFECTS OF FOREST SITE PREPARATION AND HARVESTING

Discussion Leader: J.D. Lousier, Research Branch, Ministry of Forests

It was accepted that all forest harvesting and site preparation practices promote some soil degradation and that our mandate as soil scientists and forest managers must be to minimize this degradation. Within the context of this Working Group, the degradation effects of harvesting were summarized into three areas: 1) compaction; 2) nutrient depletion through normal harvesting, increased utilization (including whole tree harvesting), redistribution and piling of slash and soil organic matter, or increased erosion and leaching; and 3) dramatic macro- and microclimatic modifications which affect soil processes and vegetation survival and establishment. While site preparation is intended to improve access to the site, nutrient availability, quality of the seed bed or planting sites, and microclimate for seedling survival and growth, and to decrease competition for the newly planted crop trees, these same techniques can accelerate nutrient depletion, can cause soil compaction, and can promote brush competition and severe microclimatic effects on seedlings.

In light of these possible problems, the responsibilities of the soil scientists are to: (1) provide information which will improve harvesting and handling techniques on site in order to reduce or eliminate the most serious degradation effects on soils; (2) make the forest managers/loggers aware of the range of remedial measures to be utilized to reduce degradation impacts caused by harvesting; (3) assess the range of site preparation options and define or describe the degradation effects or site improvement effects of these practices and advise the forest manager; and (4) provide a level of knowledge that will allow managers to maintain or enhance potential site productivity.

While remedial measures are presently utilized in attempts to reduce or correct soil degradation problems caused by harvesting and site preparation, it was felt that it was difficult to prescribe specific remedial measures for specific problems because of a lack of definition and understanding of the problems and their extent. We have a poor understanding of the threshold levels of degradation impacts; for example, we do not know what level of compaction seedling roots can tolerate, we haven't identified the levels of nutrient depletion which cause potential site productivity to decrease on a short-term or long-term basis, and we have a poor understanding of the environmental requirements of regenerating seedlings. Much of this information deficiency is a result of: (1) too little research and practical experience in successfully ameliorating soil degradation problems; and (2) the highly variable nature of degradation effects because of the inherent high variability in site characteristics and site response to treatments. While much research has to be initiated and results applied; it was felt that the most immediate solution to avoiding or reducing soil degradation effects related to harvesting and site preparation would be to upgrade our planning process given our present recognition of the problems, i.e., improving all aspects of the process: research planning, pre-harvest operational planning, post-harvest planning, implementation of responsible operational procedures, and enforcement of operational constraints. As our level of understanding improves because of research

and operational experience, our planning process will be improved and can be more effective on a site-specific or problem specific basis.

The biggest deterents to the application of present remedial measures were felt to be: (1) a lack of appreciation for the need for remedial measures; (2) a lack of understanding of operational constraints; (3) economic constraints, and (4) a lack of an inventory or understanding of sensitive areas. These roadblocks can best be overcome by expanding and developing existing programs and policies, by enforcing existing regulations, guidelines and constraints, and by holding the forest industry and the Ministry of Forests to their commitments, not by adopting new government legislation.

In order to minimize the problems associated with soil degradation caused by harvesting and site preparation, certain needs and priorities must be addressed in three areas: research and development, policies, and communications. Research/development needs and priorities are as follows: (1) a better definition and understanding of the soil degradation effects of harvesting and site preparation; (2) the development of better methods for identifying soil degradation effects; (3) a better and more extensive inventory and description of sensitive areas; and (4) the development of better planning, operational and implementation procedures. Policy priorities were felt to include: (1) benefit cost analyses of all phases of forestry are necessary to quantify economically the losses related to soil degradation; (2) rehabilitation of degraded sites and all reforestation should be completed and paid for through the revenues generated through harvesting, i.e., each timber management unit should be required to pay for itself in order to introduce a greater level of responsibility for better forest land management; (3) the implementation of the relevant policies and programs which can help to reduce or mitigate soil degradation losses must be enforced; and (4) opportunity should be created for more intensive management of our more stable and productive second growth stands, thus reducing the demand on less accessible and more sensitive old growth areas. The following communication needs were identified as necessary: (1) accelerated and more intensive education and training of the forestry community as to the magnitude of soil degradation losses, responsible land management practices and proper implementation of the necessary guidelines and constraints; and (2) promotion of greater awareness and involvement of society-at-large with regard to the soil degradation and land management problems foresters face, the costs associated with those problems, and the remedial measures and efforts required and implemented.

GROUP 2: FOREST ACCESS ROAD RELATED SOIL DEGRADATION

Discussion Leader: Andrew G. Jakoy, R.P.F., B.C. Institute of Technology

INTRODUCTION

According to the latest Ministry of Forests Annual Report the total harvested public forest land was 187 834 ha in the fiscal year of 1980-81. Road access to this much area costs hundreds of millions dollars.

We must appreciate that the "Forest without roads is the same as a library without aisles" (Ballard, 1983).

The last Royal Commission on forest policy in British Columbia pointed out that "By far the most serious environmental problems associated with logging arise from road building" (Pearse, 1976).

This type of degradation is not a soil degradation in a strict sense but may be considered as land degradation. The result, nevertheless, shows up in the reduction of the total productive capacity of the land.

Report on the Discussion of Guidelines Given to the Workshop Participants.

1) What kind of remedial measures are feasible to reduce or correct this type of soil degradation problem?

The forest access road survey and location may be broken down into three phases. These are: a) planning b) operation and c) final quality control.

a) Planning Phase

This phase is associated with the selection of a suitable route through a terrain to satisfy the management objectives.

To minimize degradation, a full watershed planning system is necessary. This planning should be carried out by a resource management team. This team should preferably belong to one organization to assure speedy and efficient

interaction between parties.

Terrain classification maps and reports, if available, should be utilized in this planning to project expected costs in the future and to avoid problem areas. The operational engineering staff should be equipped with the necessary knowledge to interpret these maps as to their scale and applicability. This calls for frequent continuing education workshops.

Supervisor engineers should promote the training of their field personnel and should assign a high priority to this.

It must be realized that there is no substitute for the conscientious field reconnaissance at all levels of route selection. This reconnaissance should utilize all possible information available to the location engineer.

The system planning should consider future forest management objectives in the selection of permanent roads, not just the present extraction of timber.

b) Operation Phase

This phase is associated with the construction of the access roads.

The construction of permanent roads must be based on horizontal and vertical grade control. On these roads hydrological work, such as culvert spacing and design, should be carried out according to accepted engineering standards (Holmes, 1982).

The machine operators should receive continuous training, preferably through field demonstrations, to increase their awareness of the problems involved with land degradation induced by heavy machinery.

c) Final Quality Control Phase

This phase encompasses supervisory inspection and rehabilitation.

Surface erosion of cut and fill slopes may be minimized by hydroseeding (Carr, 1981), a practice not widely applied in British Columbia at present.

Secondary roads are to be "put-to-bed" by ripping and re-establishment of original drainage pattern of the land wherever possible.

Landings may be ripped and revegetated but not necessarily with commercial tree species since growth return from commercial species may not be expected under these conditions.

2) What is inhibiting the application of these remedial measures?

The greatest limitation to carrying out accepted engineering procedures for construction and maintenance of forest roads, e.g. establishment of cut and fill slope stability and/or adequate right-of-way width, is in the initial cost of these measures. Each remedial measure mentioned under (1) of this discussion represents an increased initial cost in the establishment of the road.

In some cases personal unawareness of the long term effects of this type of land degradation may be a limiting factor.

Krag and Kvarv (1981), speaking for the operational engineering staff, expressed certain misgivings about the usefulness of terrain classification maps and their complicated symbols. Soil survey reports also fail to give site specific information to a location engineer.

3) Are Government policies, programs, or legislation required to correct or prevent this type of soil degradation?

Government policies on the whole in this field are adequate. The efficient interpretation of these policies is a necessity.

There is no need for new legislation in this regard.

The Fisheries Act (Canada) is a very strong act and in many areas may be applied with moderation to obtain a compromise between the parties involved.

The careful implementation of the five-year planning program of Forest and Range Resource Analysis and the twenty-year program of Timber Supply Area planning should provide an effective approach toward the minimization of land degradation associated with extensive road construction.

It is suggested that a training program to minimize land degradation is to be supported by the Government.

4) What are the research needs and priorities for minimizing this type of soil degradation?

The expenses of the taxpayers are enormous in the loss of stumpage revenue resulting from road construction. Development of an effective system is necessary to identify these costs and to reduce these costs in the long run.

There is a need for development of new logging methods to reduce the number of access roads and extraction roads. The value of "patch logging system" should be evaluated in light of the number and length of roads required.

Research in species selection is necessary to revegetate denuded sites.

There is need for more measurements to demonstrate actual erosion losses and problems associated with roads.

There is a need for several demonstration areas throughout the province where regional staff can exchange information.

More integrated studies are necessary for full watershed system planning and the efficiency of these studies should be improved.

ACKNOWLEDGEMENTS

Sincere thanks are conveyed to the participants of this workshop for their help and enthusiasm.

References

Ballard, T.M. 1983. Personal Communication.
B.C. Soil Degradation Workshop.

Carr, W.W. 1981. Surface erosion: hazard assessment and its control.
In A.P.D. Tech. Paper 6. T. Vold (ed).

Holmes, D.C. 1982. A manual of roads and transportation.
1982 Revision. Vol. 1 and 2. B.C.I.T.

Krag, R. and Einar Kvarv, 1981. Soil factors:- their relative value in road locations and in selection of yarding systems.
In A.P.D. Tech. Paper 6. T. Vold (ed).

Pearse, Peter. 1976. Report of the Royal Commission of forest resources.
Vol. 1. K.M. McDonald, Victoria, B.C.

Department of Fisheries and Oceans. 1979. Manual of fisheries acts and regulations, Ottawa, Ont.

Ministry of Forests. 1981. Report of the Ministry of Forests for fiscal year ending March 31, 1981. M.O.F. Info. Div. Victoria, B.C.

GROUP 3: LAND CLEARING AND LINEAR DEVELOPMENT

Discussion Leader: W. J. Hastie, Hardy Associates (1978) Ltd.

SUMMARY OF DISCUSSION

1. What kind of remedial measures are feasible to reduce or correct soil degradation?

Soil degradation problems associated with both land clearing for agriculture and linear transmission line and pipeline developments include erosion, soil mixing, compaction and puddling. It was felt that the best measures for minimizing these problems were preventative in nature. Such measures as use of proper sized machinery and equipment for clearing (including hand clearing and in some cases no clearing), proper timing of clearing and construction activities to avoid wet soil conditions and reclamation planning and careful consideration of route locations to avoid sensitive terrain conditions should be included in the planning stage of a project and followed up during construction. Many specific measures exist to minimize the above problems but site specific planning is needed to fit the best measures to site conditions. Both site conditions and appropriate soil degradation control measures will vary from region to region and also with terrain, soil and land use in a particular area. It was noted that recently some linear development projects in B.C. are now carrying out site specific studies to minimize soil degradation and specific control measures are included in project plans.

2. What is inhibiting the application of these remedial measures?

Although soil degradation control measures are known and sometimes planned for it was clearly felt there was a lack of follow through by project engineers contractors and/or landowners during project construction. At the same time it was felt that there was a general lack of consistant regulatory

enforcement of the use of soil degradation control measures although examples of enforcement during project implementation were cited.

It was felt that the lack of follow through by project personnel was in part the result of the inability of soil scientists to quantify the costs and benefits of implementing soil degradation control measures and thus justify them to non soils personnel. In the case of land clearing and linear development the pressures to meet schedule deadlines for economic, contractural or other reasons often precludes consideration of good soil management.

The lack of consistent regulatory enforcement is partly the result of the variety of agencies involved depending on the location, current land use and land ownership (including the Ministries of Agriculture, Lands, Environment and Forestry).

It was also suggested that the presence of a qualified professional on site during construction of projects would help to ensure soil degradation was minimized.

3. Are Government policies programs or legislation required to prevent or correct soil degradation?

It was felt that with respect to land clearing for agriculture the existing program of agricultural extension, given additional support and funding could provide the necessary site specific guidance and follow through to minimize soil degradation. Ministry soils specialists would be required in each region with a mandate to advise and assist landowners or lessees during the planning stage and to monitor and enforce good clearing practices during the clearing operation.

With respect to linear developments which traverse a number of jurisdictions as well as a great variety of terrain and soil conditions it was felt that an agency was required which could ensure that the necessary site specific planning has been conducted and enforce the implementation of these soil management plans. Such an agency could provide a focus for soil management throughout the province and ensure that soil degradation control measures are consistantly and fairly applied. This agency would also require regional soils specialists to assess and enforce site specific concerns and remedial actions. Compliance could also be ensured by requiring the inclusion of soil degradation control measures in contract bid documents.

4. What are the research needs and priorities for minimizing this type of soil degradation?

In a general sense it was felt that we (soil scientists) need to clearly define how much and how significant (cost/benefit) soil degradation problems are in B.C.

Until we can answer this question in meaningful terms to project engineers, farmers and other non soil scientists it will be difficult to implement soil degradation control measures. It will also be difficult to justify more stringent regulatory control.

Specific research needs were also noted including:

- investigation of the effects of existing construction and reclamation techniques on the variety of landscapes in B.C. that may be sensitive to soil degradation; and
- evaluation of equipment and techniques to minimize soil clearing or linear development (e.g. machinery to minimize soil mixing).

GROUP 4: SOIL SURFACE EROSION (WATER)

Discussion Leader: G.G. Runka, G.G. Runka Land Sense Ltd.

Definition - Removal, transportation and redeposition of materials.

Bias - Perceived agricultural bias, but attempted integration of use considerations.

Problems and Types of Erosion

- Sheet/rill and streambank erosion dominant concerns
- Key use areas a) agriculture (open soil surfaces), b) forestry (site treatment prescription), c) urban and engineering (erosion of earth contained structures, transportation roads and ditches), d) fisheries (sediment impact).

1. Remedial Measures

- reduction of slope lengths
- contouring
- crop rotation
- crop suitability (use the soil map)
- underground drainage systems
- stubble management
- soil management practices
- winter treatment and forest site prescription
- mapping of erosion prone areas
- slash removal determined more carefully
- logging road selection and hydrologic control structures

2. Inhibiting Factors

- perceived economics, historical and cultural trends
- jurisdictional and tenure considerations with respect to land and water use

3. Government Involvement

- field demonstration regarding erosion potential and problems
- integration of research and demonstration
- incentive programs for erosion control measures
- land management plans before funding and loans provided by government agencies
- need for more soil specialists in the field

"Preventative measures should be given first priority, with education of land users the first step."

GROUP 5: ORGANIC SOILS AND WATER MANAGEMENT

Discussion Leader: A.L. van Ryswyk, Agriculture Canada, Kamloops

INTRODUCTION

The workshop group consisted of eight members; two from B.C. Ministry of Agriculture and Food, one from B.C. Ministry of Environment, one from the University of British Columbia, two from Agriculture Canada and two from private industry. The main discussion centered on organic soil degradation found under intensive cropping as practised in the lower mainland and Vancouver Island where class 1 and 2 climate predominates. Reference was also made to soil problems found under forage production in the B.C. Interior where class 4 and 5 climate dominates. The group had the benefit of excellent updated background information in Mr. R.C. Wood's paper (this proceedings).

REMEDIAL MEASURES

The major degradation problem is loss of organic material, manifested mainly as subsidence, following drainage and subsequent cultivation. Subsidence is rapid in the first 5 to 10 years due to water removal, shrinkage and decomposition. This is followed by slow decomposition through oxidation and enzymatic action where average subsidence rates are 2 to 3 cm/year at this latitude. Subsidence is associated with further drainage problems, loss of structure and permeability and eventually exposure of mineral substrate.

Subsidence is continuous but can be reduced by certain management practices. Water control facilities should be designed to maintain a water table as high as possible for best growth of the specific crop and for good trafficability to prevent compaction. This will reduce aeration and subsequent oxidation. Observations indicate that the best drainage control is not always practiced.

Frequency of tillage, particularly rotovation, should be minimized to reduce aeration.

Recent studies have shown that prescribed applications of copper can substantially reduce enzymatic breakdown of organic soil material.

Winter flooding is frequently allowed to promote decomposition of crop residues. However, it may also enhance soil borne disease organisms. Soil decomposition may be reduced but on excessively tilled land, a colloidal surface layer can develop which impedes water movement into the soil. Drainage time is increased and cropping season shortened. If the water is drained off, surface erosion loss of finely divided surface material can occur on very low slope gradients.

The use of cover crops has not been thoroughly explored for this area. It was suggested that the roots of a cover crop would reduce soil oxygen and hence oxidation. The crop should prevent surface colloid formation, structure deterioration and surface erosion. Subsequent incorporation of the crop may help rebuild the soil but may also cause a flush of microbial growth to further decompose organic material.

The presence of restricting layers, high in mineral content, have been found in certain organic soils. Crops do poorly where the layers are shallow. Fine colloidal material may eluviate and further reduce root and/or water permeability of the layers. The role that inherent organic soil characteristics play in crop production is not always fully understood.

Newly developed organic soils may require different management, water control and cultivation practices than those cropped for long terms.

Degradation problems on the perennial forage producing organic soils of the Interior were not perceived to be as great as those of the lower mainland. However, water control is still a major consideration not only for the water removal aspect but also for water table maintenance. During the drought of the thirties, many organic soil areas dried out to the point that fires occurred, some lasting for more than a season. The organic soil resource was nearly totally destroyed in these areas. In other areas it took two or more years to replenish the water table for good forage production.

INHIBITIONS

The development of improved drainage districts that could better coordinate the regional drainage system more closely with the seasonal needs of specific farms was perceived as a major inhibition. This also relates to government policies.

More extension work through demonstration and information exchange is needed to promote practices known to be beneficial. Liason between extension and research organizations already exists but more is needed to resolve such questionable practices as excessive tillage, winter flooding, use of cover crops and to determine the role of soil type (e.g. presence of restricting layers). This will lead to strengthening the links of the research-demonstration-extension chain.

A better understanding of soil characteristics affecting crop growth is needed so that the job of soil classifiers and mappers is made easier. Soils of drainage districts need to be classified and mapped more intensively with the specific view to identifying problem areas, such as those where restricting layers will affect crop production and those that are likely to decompose first to expose mineral soil. This will require a close liason between research, extension and pedology personnel.

GOVERNMENT POLICIES

Existing government policies make it difficult to plan and develop drainage districts. The present provincial water act needs improvement so that conflicts between wetland resource users (including mining, municipal water district, wildlife and recreation interests) can be resolved at the planning stages before development proceeds.

A positive approach to encouraging better management practices would be tax or subsidy incentives for performing specific beneficial items such as the use of copper or maintenance of prescribed water tables.

Better financial support for research and extension activies will be needed if we are to learn more about organic soil management and put it into practice.

RESEARCH

Research into the nature of restricting layers has begun by a U.B.C. graduate student. The Terrestrial Studies Branch, B.C. Ministry of Environment is aware of the need for better characterization of organic soils and for more intensive soil mapping on drainage districts. This work needs to be encouraged and continued at a higher level of activity.

Research needs to be done to evaluate the effects of various management systems on soil degradation.

Better designs of drainage systems need to be developed so that the regional system can better meet the seasonal needs of the individual farm.

Research is especially needed to evaluate the use of cover crops to reduce degradation under typical conditions of the lower mainland and Vancouver Island.

The chain of research-demonstration-extension is being established among various agencies and these links need to be continued and enhanced if the productive life of the organic soils is to be preserved as long as possible.

GROUP 6A: SOIL MANAGEMENT - ORGANIC MATTER LOSS, COMPACTION, EXCESSIVE TILLAGE, STRUCTURE LOSS

Discussion Leader: H.A. Luttmerding, B.C. Ministry of Environment

This workshop group consisted primarily of persons with agricultural orientation, consequently discussion of soil management related mainly to agriculture. The specific soil management concerns (organic matter loss, compaction, etc.) were individually discussed in the context of the four questions to which this workshop group was asked to respond.

Question 1) What kind of remedial measures are feasible to reduce or correct this type of soil degradation problem?

Organic Matter Loss - General comments related to the fact that in B.C. there is very little hard data on which to assess whether, in fact, serious organic matter losses are occurring. Other comments indicated some soils are naturally low in organic matter and management to increase organic matter may be more of a concern than controlling losses per se. Agricultural practices may already be increasing organic levels in some areas. A general comment was made that any practice which enhances root biomass production is good.

More specific remedial measures discussed included: 1) control and reduce erosion, 2) use of cover crops to increase organic matter production and control erosion, 3) appropriate crop selection and rotations, i.e. less emphasis on monoculture and more emphasis on rotations which include grasses and legumes, 4) limit tillage as much as possible and choose appropriate equipment, 5) incorporate crop residue (don't burn), and 6) apply manure where available.

Soil Compaction - General comments related to the fact that compaction is widespread and probably increasing. Another comment suggested that some B.C. soils (e.g. in the Peace River) are naturally compact and management relates to methods of making them

less compact rather than controlling increased compaction on naturally non-compact soils.

More specific and feasible management methods suggested for compaction control included: 1) limiting field operations (e.g. less tillage) and using appropriate equipment, 2) conduct necessary field operations during periods when compaction is likely to be minimized (e.g. stay off fields during wet periods), 3) organic matter management to maintain levels, 4) appropriate crop rotations, particularly those that include deeper rooted crops to improve subsoil porosity and permeability, 5) water table control to facilitate structure formation, 6) limit livestock access to periods when soils are not wet, and 7) maintain surface trash (or cover crop) to protect from raindrop splash.

Excessive tillage - The most obvious remedial measure to counteract this soil degradation process is to promote minimum levels of tillage as required by the crop grown. Some crops do not need a fine seedbed, for example. Herbicide use or accepting the presence of a few weeds may be alternatives to numerous tillage operations.

Structure Loss - This soil degradation problem was not discussed in detail because of time restraints. A general comment was made however that if the previous degradation problems (organic matter loss, compaction and excessive tillage) are controlled or improved, then structure improvement will also result.

Question 2) What is inhibiting the application of these remedial measures?

In general the work group agreed that economic conditions are most inhibiting the application of remedial measures. For example, encouragement by government and other agencies through marketing of programs to produce high volumes of certain crops promotes monoculture (e.g. grain, corn). Absence of infrastructure in some cases is also inhibiting (e.g. no market in area for some of crops in rotations, such as grasses and legumes, because livestock production is located elsewhere). Livestock manure is not returned to the land in these cropping areas while in others (where livestock production is intensive), its disposal may be a serious

problem. Another comment, strongly supported by the group, was that remedial measures required to counteract soil degradation are often not cost-effective in the short-term and that producers frequently cannot afford to institute them and still remain economically viable.

Many producers still perceive that good land management requires multi-tillage operations (i.e. a producer with clean, weed-free, "black" fields is perceived as a good farmer).

Question 3) Are Government policies, programs or legislation required to correct or prevent this type of soil degradation?

The workgroup in general agreed that action at governmental levels are required although no specific actions were identified. Some form of incentives to make remedial actions financially attractive in both the short and long-term are needed. Educational programs to foster awareness of the consequences of soil degradation were highlighted as a need. Included in these were demonstrations that exhibit the benefits of soil conservation measures and also indicate they need not necessarily be expensive. Also highlighted was the shortage of extension staff to advise on and promote proper soil management.

Question 4) What are the research needs and priorities for minimizing this type of soil degradation?

The following were identified as research needs in the context of soil management. The order of the recommendations do not indicate priority.

1) Research into changes in organic matter content in soils, particularly in "critical" areas (e.g. Peace River area). The research should address both the quantity and quality of the organic matter (e.g. some forms of organic matter are more conducive to resolution of fertility problems while others are better for structure improvement).

2) Research into increasing or maintaining water stable aggregates during the year.

3) Research into subsoiling - how, when, what depth, how often and

its relation to other aspects of land management.

4) Research into the levels of organic matter required in soil to minimize compaction and structure deterioration.

5) Research into the minimum tillage requirements for maintaining crop production, e.g. on organic soils.

6) Research into the implications of zero tillage to crop production in B.C. Is it viable, what are the limitations, should it be promoted, etc.

As mentioned previously, the working group was almost exclusively agriculturally oriented. The lone forestry person indicated that soil management (O.M. loss, compaction, structure deterioration) are also serious forestry concerns and that many of the preceding comments can also be applied to forestry.

GROUP 6B: SOIL MANAGEMENT - ORGANIC MATTER LOSS, COMPACTION, EXCESSIVE TILLAGE AND STRUCTURE LOSS

Discussion Leader: Charles Rowles, Dept. of Soil Science, U.B.C.
Secretary: Art Bomke, Dept. of Soil Science, U.B.C.

Discussion group 6b was enthusiastic and diverse as to specializations, interests and experience. It included individuals from Industry, Consulting, the Land Commission, Teaching, Research and Extension in British Columbia, as well as out-of-Province representatives from the Departments of Soil Science at the Universities of Alberta (C.F. Bentley) and Saskatchewan (M. Grevers). There were a number of students present from the Department of Soil Science at U.B.C. who also contributed significantly to the lively discussion.

It was noted at the beginning of the discussion that excellent papers had been presented during the previous day dealing with the four main topics to be considered: organic matter loss, compaction, excessive tillage and structure, and that these detailed statements would be included in the Proceedings of the workshop. Therefore, it was agreed that the group's discussion would be related, in the main, to what was seen and noted on the morning's Field Tour. It was also felt that since soil organic matter is related in important ways to the other three topics, special emphasis would be given to it in relation to the other topics.

1. What kind of remedial measures are available to reduce this type of soil degradation problem?

It was noted that during the field tour extensive areas of bare, unprotected and flooded soils had been seen, particularly in the level, flood-plain areas of the valley. It was felt that although this might not contribute to accelerated soil organic matter loss, it provided no opportunity for soil organic matter

accretion or structure improvement through surface or root effects. It was also felt that there would be serious soil degradation in the form of structure loss and surface compaction due to raindrop effects and loss of soil by water and, in one or two instances, wind erosion as well. Also, during the tour, little or no evidence was seen of attempts to utilize trash on cover crops to provide organic matter and soil protection except for the small experimental cereal seedings between the strawberry rows at Site No. 4, D.A.T.E. Project.

The group recognized that the introduction of cover crops would sometimes be difficult and present problems. Thus, in the lowland soils, improved surface and subsurface drainage would apparently be a prerequisite in most instances seen. Also, in the lowland areas it was felt that excessive and untimely tillage with heavy machinery, including rotavation, were important factors contributing to soil degradation in both mineral and organic soils. It was generally felt that remedial measures that should be stressed were improved drainage, reduced and timely tillage, and greater use of mulches, cover crops and green manures.

In the case of the upland soils, it was also felt that greater use of cover crops and other means of soil protection should be stressed as remedial measures to prevent soil degradation. In the case of Site No. 4, the D.A.T.E. Project, the apparent very beneficial effects of the experimental cereal cover crops and the freshly fallen leaves between the strawberry rows was noted by the group. The difficulty of combining cover crops and other forms of surface soil protection with strawberry and other row crops was recognized but it was felt that such procedures should be pursued further as possible remedial measures along with the other practices observed. In this regard it was suggested that in some stony and shallow upland soils the installation of drainage using modern equipment and procedures might prove difficult, very expensive, or impossible. It was also felt that slope steepness and length, along with other criteria should be used to develop production limits and guides in the choice of crops and management practices for different soils. Also, continued and even greater emphasis should be placed on the permanent seeding of waterways, gullies, roadsides, construction sites and other seriously disturbed soil areas.

2. What is inhibiting the application of these remedial measures?

The group felt that the traditional concepts of "the limitless land resource" and "exploitation in Canada" were important factors in inhibiting application of soil conservation measures and that efforts must be continued to overcome these misconceptions. Another misconception held by producers that it was agreed must be overcome is that "a good farmer must have his soil clean and bare" which leads to excessive cultivation. Also, it was suggested that some believe it is necessary to have their soils saturated or flooded during the winter months to kill nematodes and other undesirable organisms.

It was agreed that lack of communication between the many specialists and producers concerned with the soil resource was an important factor in inhibiting introduction of remedial measures. In this regard, the group was very pleased to note the large number and diversity of the individuals present at the workshop but felt that the attendance of more "non-soil specialists" would be desirable.

The group agreed that "hard facts" were important in selling remedial measures to producers and suggested that perhaps not all available data was being utilized effectively. However, it was agreed that more research and demonstration data is needed.

It was felt that in some instances untrained and inexperienced individuals with no appreciation of crop selection, soil management or remedial measures have and are undertaken farming operations for the first time. In such instances, serious soil degradation may take place immediately, even before preventative or remedial measures can be considered or applied. It appeared that this may have been an important factor contributing to the very serious soil degradation seen at Site No. 4 of the morning's tour.

It was suggested by the group that for B.C., preparation and introduction, by region or area, of specific, practical manuals covering such topics as recommended use, crop selection and management practices for different soils and stressing measures to prevent and remedy soil degradation would be of assistance in overcoming inhibition to the application of conservation measures.

It was also noted by the students present that teaching activities relative to soil degradation and remedial measures should include appropriate onsite field training and experience in such things as soil survey, land classification, management and conservation.

3. Are Government policies, programs and legislation required to correct or prevent this type of soil degradation?

It was agreed that Government policies, programs and legislation are required to correct and prevent this type of soil degradation. In particular, it was felt that greatly increased Government support for research, demonstration and extension relative to soil degradation and its prevention is needed. This includes more scientists, facilities and funds for research and travel in all these areas.

With regard to the role of Government in preventing and correcting soil degradation, a current project in Saskatchewan was noted. This project involves the expenditure of $25,000,000 over a period of 5 years for co-ordinated research and extension including large scale experiments and demonstrations undertaken by producers themselves.

The concensus of opinion seemed to be that more could be accomplished through education and demonstration than by legislative requirements and laws although in some extreme situations enforcement by law might be necessary.

It was noted that in British Columbia the Government had provided a more leadership and support for the preservation of agricultural land than it had for preventing soil degradation and developing and introducing remedial measures. The group agreed that as an urgent matter, the Government's attention should be directed to the latter needs.

4. What are the research needs and priorities for minimizing this type of soil degradation?

It was agreed that there are many research needs with high priorities but it was also felt that improved use could be made of the research information already available. It was also suggested that although soil degradation is being stressed at this workshop, the research should be directed toward quantifying the overall effects of the use and management of the soils of British Columbia and that in some soils and situations, these effects would be positive.

High priority subjects requiring research in British Columbia suggested were:

i. Further comparisons of virgin soils with the same soils under different uses and management practices for different periods of time with respect to:

(a) The nature and amount of organic matter, nitrogen and other elements.

(b) Their physical characteristics including structure and compaction.

(c) Their biological populations and activities.

(d) Their productivity.

ii. The establishment of longterm experimental plots to study the effects of different uses, cropping and soil management practices on major soils.

iii. Further research to determine the best use, crop selection and management for major soils of the Province.

iv. Extended research and demonstration in the use of cover crops, green manures, and mulches in the prevention of soil degradation, i.e., biological controls are preferred over engineering controls.

In conclusion, the group wished to congratulate the organizing committee on the excellence of the Workshop, including the Soil Tour. It recommends that such workshops be continued. In this regard, the students in the group suggested that special consideration be given to selecting positive titles for the workshops.

GROUP 7: ACIDIFICATION

Discussion Leader: J.H. Wiens, Terrestrial Studies, B.C. Ministry of Environment

INTRODUCTION

Acidification problems and potentials in B.C. were reviewed by region and source. Highlights included documented pH reductions due to N fertilization in Okanagan orchards and in the Peace River area, severe acidification and vegetation effects (prior to 1934) due to non-ferrous metal smelting and SO_2 emissions in the Kootenays (particularly around Trail, B.C.), potentials for effects in the N.W. due to aluminum smelting (Kitimat), potentials for effects resulting from natural gas processing (e.g. Fort Nelson, Taylor, Chetwynd) and pulp mill emissions (many locations), and potentials for impacts on already acid south coastal soils from industrial emissions, auto emissions, heavy N fertilization and trans-boundary transport from N.W. United States sources.

REMEDIAL MEASURES

T o general approaches can be and are being taken to remedy soil acidification. The sources of acidic inputs may be controlled, or soil ammendments (e.g. lime) may be added to counteract acidification. Additionally, rates of water application affect base leaching and soil acidity. Control of water application is thus another remedial measure.

The feasibility of applying one or more methods depends in good measure on economics. It is technically feasible to control air emissions further. It is possible to reduce N fertilization rates, change formulations of N fertilizer, or increase crop use efficiency of N fertilizer by timing of applications and soil testing in some areas. It is also feasible to lime most soils in order to maintain or restore pH levels. As well, better irrigation scheduling and more efficient methods of application (e.g. trickle irrigation), have reduced excessive water application. However, the costs of reducing emissions, not fertilizing as heavily, changing fertilizer formulations, transporting liming materials from sources to areas of need etc. are often considered too high by the individual firm or even government regulation agencies.

FACTORS INHIBITING APPLICATION OF REMEDIAL MEASURES

As noted above, economics have a great deal to do with application of remedial measures. Particularly when costs are considered prohibitive, the true benefits of applying these measures (and/or true costs of <u>not</u> applying

them) may have to be developed. Issues which may require particular attention include long-term and secondary benefits and costs. However, often biological interactions and impacts are not known. Thus it is even more difficult to document costs.

Liming materials are not readily available at all places where they are needed. Transportation costs are high. This cost is inhibiting widespread use in some areas (e.g. Peace River).

Research, documentation, and agreement by soil scientists and others on the nature and extent of the problem, itself inhibits application of remedial measures. Consistent use of reliable methods even for soil pH measurement has not always been the case. Clear trends in soil acidification are thus difficult to document. The nature and magnitude of different crops and vegetation species response to acidification is still a matter of research as are environmental sensitivites. Certainly the relationship between source emissions, pollutant transport/deposition and soil acidification is a topic of disagreement.

POLICIES, PROGRAMS AND LEGISLATION

Policies and programs were emphasized to a greater degree than legislation. Particular interest was focussed on provincial government policy regarding assistance for use of liming materials. There was strong support expressed for a policy which would encourage greater use of lime in areas where costs are high and acidification is becoming a limitation to production. The Peace River area, where 40% of the soils are acid, was noted in particular.

Expressions of support were voiced for strong enforcement of regulations regarding industrial emissions which are precursors to acid precipitation. The rapidly increasing incremental costs of industrial emissions controls as complete control is approached were noted.

Extension, demonstration and research were recognized as needing particular support if effective policies are to be developed and implemented. The author notes that acidification due to N fertilization was a focus of discussion of the group. Since regulation of N use would hardly be considered, research, extension and demonstration requires particular support.

RESEARCH NEEDS AND PRIORITIES

Liming is widely practiced to remedy soil acidification. However, research is needed on both the practice and economics of liming. Practice includes such matters as effective incorporation into the root zone (e.g. of orchard trees). Economic issues include transportation costs and effectiveness of various materials, plant response and particularly benefits of application to production on various soils etc.

There are still many research needs dealing with uncertainties of natural vegetation and crop responses to acidified soils. These range from questions of Al, Mn, Fe and trace metal solubilities and effects on plants, to base status and microorganism activity. These must be addressed both from the basic soil chemistry and plant physiology perspective, as well as from a regional soil fertility and crop response point of view.

Nitrogen fertilization effects on soil acidity are a serious concern because of present and anticipated rates of use. Well planned, long-term, field experiments are needed so that contributions of this source can be determined and good management practices developed.

The source of wide differences in soil pH over short distances in some areas, particularly orchards were noted. The method of pH measurement should be reviewed with the objective of developing firm guidelines on the best standard methods. Particular concern is for the effects of fertilizer salts and the need for the method to take this into account (e.g. measure in $CaCl_2$). Also requiring study are the effects on pH of methods of sampling and sample handling.

The value of laboratory buffer methods for predicting lime requirements have been documented for many areas. Their applicability to B.C. conditions should be verified and calibrations should be checked.

Finally, there is a real need for development of better information on the distribution of problems of soil acidification and trends or changes over time. Along with information on the occurrence of problems there is a need to identify areas of sensitivity and potential impacts, based on both soil properties (e.g. textures, CEC, exchangeable bases, organic matter content) and on sources of acidifying inputs.

GROUP 8: MASS MOVEMENT

Discussion Leader: R. Townshend, Research Division, MacMillan Bloedel Ltd.

Remedial Measures:

- Identify sensitive areas prior to forest development.
- Either avoid sensitive areas or apply measures to reduce the potential for mass movements.
- The frequency and intensity of road induced landslides, in sensitive areas, could be significantly reduced through application of current knowledge and technology to road network planning, construction practices and maintenance.
- Selective harvesting, where practicable, could reduce mass movements associated with tree root deterioration.
- Timber harvesting systems, which avoid or reduce ground disturbance, could reduce the potential for mass movements in sensitive terrain units.

Application Hindrances:

- Lack of awareness or concern.
- Poor communication at all levels between planning and operational staff.
- Lack of adequate training of operational staff.
- Failure to use a holistic approach in planning forest development.
- Lack of adequate or available funds for suitable equipment, integrated resource planning, training, inventory, research, etc.

Policies, Programs and Legislation:

- Government policies, programs and legislation are required to prevent or reduce the potential for mass movements associated with forest development in sensitive areas.
- Since many areas have unique terrain characteristics, constraints should be applied in the form of guidelines rather than stringent rules.

Research Needs:

- Analysis of existing landslide data to develop operational guidelines on a regional basis.

- Studies to assess the relative importance of tree root deterioration, compared to ground disturbance, as an initiating factor of landslides in harvested areas. Of particular concern is ground disturbance associated with cable logging systems (yarding trails, direction of yarding, deflection, orientation of large gullies, etc.).
- Long term programs to monitor mass movements and to identify, evaluate and control mass movement processes.
- Long term regional studies to determine the effects of rapid mass movement processes on forest site quality and other resources.

SUMMARY AND PERSPECTIVE OF THE B.C. SOIL DEGRADATION WORKSHOP

L.M. Lavkulich, Dept. of Soil Science, U.B.C.

SUMMARY

Soil degradation is a serious and complex problem, not only in British Columbia and Canada, but, indeed, the world. As society continues to demand more from the soil resource, man continues to apply new technology to manipulate the soil to produce more. Much of the applied new technology is for short term economic gain and much of the effects of this new technology is little understood as to its long term effects on the soil. The fact that soil and land degradation is acknowledged to be serious is attested to by the number of people attending this workshop.

During the morning session the workshop attendees had the opportunity to obtain three views. First, of soil degradation across Canada, second, land degradation in British Columbia by forest practices and, third, by agricultural activities.

Dr. Coote summarized the soil degradation problem across Canada. In his presentation he documented the effects of erosion by wind and water, compaction, loss of organic matter and fertility, acidification and salinization. Dr. Coote presented statistics on the loss of productivity resulting from soil degradation. This degradation is a real economic burden to the people of Canada, for not only does Canada lose products for home consumption and trade, but directly and indirectly the people of Canada are paying for reclamation projects. He gave us a perspective as to where we are going if we continue our current agricultural practices.

There is a dilemma! Economics dictate that we must increase productivity of the land. As an example, we add fertilizer as one management tool to increase production; this results in potential soil acidification which in turn must be remedied as this decreases productivity and affects micro-nutrient imbalances.

Mr. Young acknowledged that, as a result of forestry practices, soil degradation is occurring in the province of British Columbia. He illustrated the effects of construction of roads for timber harvesting, methods of logging and construction of landings and the resultant erosion and soil compaction. Mr. Young emphasized that British Columbia needs every hectare of land, especially high quality land. Contrary to popular belief, high quality land for forestry is limited. High quality land in British Columbia is being degradated by forest operations but, more seriously, land is being lost to agriculture and urban settlements. The Ministry of Forests, as well as the industry, are taking positive steps such as scarification, new methods of logging, prescribed burning and road maintenance to minimize land degradation effects.

Dr. MacEacheron, addressing soil degradation as a result of agricultural practices, gave examples of soil erosion in the Peace River

region, compaction and the need for proper drainage in other parts of British Columbia and acidification of soils in the Okanagan. He indicated clearly that soil degradation is of low priority for governments. The problems of soil degradation will intensify as we expect more from the land. He asked a pertinent question - "How much degradation can we tolerate"? He urged soil scientists to take a multidisciplinary approach to look at the problem of soil degradation. We must look at the "through-put" as well as the "capital-stock" - the soil resource. Dr. MacEacheron suggested the use of systems approaches and simulation modelling in attempts to solve soil degradation problems. He also urged that social and economic inputs are needed in order for people, in general, to recognize the seriousness of the problems of soil degradation.

What I perceived from the three speakers was that soil and land degradation are real and recognized, that we as soil scientists must look at the entire soil resource, not only its inherent productivity but also its allocation to various uses. We must also do a better job of communicating our concerns with our public and our allied disciplines. We must put forth legitimate concerns in terms of social and economic consequences.

The rest of the workshop addressed more specific kinds of soil degradation occurring in British Columbia.

Messrs. van Vliet and Novak outlined the principles of wind and water erosion. They concluded that there was probably little serious wind erosion occurring in British Columbia. There was more concern expressed about water erosion, particularly in the Lower Fraser Valley and in the Peace River region. These latter two areas are most susceptible to water erosion. There is insufficient data for assessment of both wind and water erosion.

Dr. Hoyt informed the group that we do have acid rain in British Columbia and it is becoming more acid. Normal pH of rain is 5.7, Vancouver's rain has a pH of around 4.9. Coupled with nitrogen fertilization, especially with soils of low cation exchange capacity, acid rain is causing problems with regards to aluminum and manganese toxicities. Dr. Hoyt also pointed out that from 1967 to 1978 there has been an increase in acidity in soils of the province.

Messrs. Keng and Lowe addressed the issue of loss of organic matter and the apparent shifts in the quality of organic matter. Declines in organic matter content as a result of cultivation also decreases soil fertility, cation exchange capacity, water holding capacity and water stable aggregates. Monoculture, without organic matter additions, promotes organic matter degradation.

Dr. J. de Vries discussed soil compaction throughout the various regions of the province. He indicated that soil compaction is serious in most parts of British Columbia, with the exception of the Okanagan.

Drainage and cultivation of soil at the right water content does much to prevent compaction. By minimizing compaction, roots of crops can exploit the soil for needed nutrition. Dr. de Vries stressed that the key to good soil physical conditions is water management.

On the topic of subsidence of organic soils, Mr. G. Wood indicated that excessive drainage can cause subsidence of up to 2 to 3 centimetres per year. Subsidence not only is a loss of valuable organic matter, but also causes failures of drainage systems. Mr. Wood indicated that the process is little understood and that there are conflicting results in the literature regarding management practices and their effects on subsidence.

Water management, which had been touched upon by Messrs. de Vries and Wood, was expanded by Mr. M. Driehuzen. Water management is important at regional and local levels as well as on site to prevent soil degradation by many activities. Regional water management is often not seen as an important issue but without regional water management farm drainage systems are ineffective. Water management is important for erosion control, prevention of compaction and to halt accelerated subsidence of organic soils.

Mr. Miller stated that large areas are affected by linear developments in British Columbia. The most serious problems he identified were: soil erosion along right-of-ways, subsidence of areas of permafrost, cut-slope induced mass movements and elevated soil temperatures. Mr. Miller stressed the importance of planning projects and the early identification of sensitive areas.

Land clearing also leads to soil degradation. Mr. Kline identified major problems in the Central Interior. The use of heavy equipment and the effects of wind-rows on soil productivity were highlighted. Also, the time of year that clearing takes place should be matched to soil conditions. Many of the effects of land clearing have long term implications for soil productivity and management.

Dr. T. M. Ballard addressed the issues of degradation effects of forest harvesting and site preparation. He stated that some "degradation" effects may be beneficial, e.g. mixing of soil organic matter with mineral soil or prescribed burning to release some nutrient capital in overly thick forest floors. He stressed that timing of operations such as winter logging may decrease soil degradation. Dr. Ballard also highlighted the importance of planning for site specific operations to minimize impact and to identify sensitive areas, both of which are often difficult to quantify before hand.

With regards to access road related degradation problems in forestry, Mr. Carr also stressed the importance of planning the access road locations. There is no question that access roads lead to mass wasting. It is important to maintain most of the original water ways to prevent water build-up along roadways.

Dr. Ryder brought to the workshop's attention the importance of the time element in land degradation by mass movements. Mass movements are natural phenomena and have been on-going since the Pleistocene. What is important to consider are the effects of poor planning and management in sensitive areas. Also, management can accelerate mass movements.

Who pays? Do we need legislation? These were the two main themes developed by Mr. Bertrand as he addressed the topic of "towards soil conservation in British Columbia". Mr. Bertrand stated that the public must pay for soil conservation as the farming community is unable to. Further, the need for legislation was expressed to ensure soil conservation.

The major themes that were developed by the speakers were:

1. Soil degradation is a serious problem in British Columbia as it is in Canada and many parts of the world.

2. Soil degradation occurs in agriculture, forestry, in linear developments and in all activities which may be considered "managed" systems.

3. Planning projects before initiation and a holistic approach to problems with systems analysis and simulation modelling would possibly alleviate many potential degradation problems.

4. Water management is a key to soil management.

5. Communication with all soil science public is essential.

6. Who pays?

PERSPECTIVE

The issues and concerns presented at this workshop by the various speakers are real. Many of the problems should not be problems as we have the technology and know-how not to cause these soil degradation problems. We are not looking at the soil resource holistically and as a system, nor are we effectively communicating with our public in terms of social and economic losses caused by soil degradation over the long term.

However, let me hasten to state that we have not done an altogether bad job. There is, however, room for improvement. The fact that soil scientists and others recognize the problems, are attempting to offer solutions and discuss them openly, is a step in the right direction.

Soil scientists have a more difficult challenge than either "pure" scientists or our colleagues in agriculture and forestry. We have to "sell" our science as both a pure and applied science. Scientists

outside of agriculture and forestry sell their science to the public and to governments on the grounds of expanding knowledge. This is accepted by their public. Agricultural and forestry scientists justify their science mainly on the basis that advances in their science increase production and, hence, the economy. Research and demonstration in the area of soil resources, in the eyes of the public and governments, costs money with no direct apparent economic gain and simply to gain knowledge has not been effectively sold. This is one area where we could do a better job of communicating.

I think we have to look at the total soil resource of the province and not continue the narrow view of this is agricultural land and this is forest land and so on. As we heard today, many of the problems facing the agricultural land base also affect the forest land base via erosion, alienation, compaction, etc. We urgently need a soil conservation plan for all of our soil resource and we need to document and attempt to quantify the social and economic costs if we do not. If we develop policies and legislation for one sector, e.g. agriculture, we simply shift the problems to other sectors of our economy that require a land base. Producers have to produce in our system of government. Documentation of problems will not help them produce. As I stated earlier, many of the examples of soil degradation we have seen and heard of over the past two days should not be occurring as we have the knowledge and the technology to prevent many of these problems. We do need cooperation, coordination and communication to alleviate our soil degradation problems. As van Bavel stated in a 1977 article in the magazine "Science", we are solving our problems by substituting oil for soil. I believe the same applies to many of our soil degradation problems. We know that certain practices cause degradation and we hope "oil" will cure the problem.

Several speakers during the workshop sessions raised the question of who should pay for soil degradation, particularly in the agricultural sector? I ask the question - who pays for land reclamation in the mining industry, for land degradation in the forest industry, for water and air pollution in the manufacturing industry? Indirectly, we all pay by lower economic productivity which affects our balance of trade and by a less pleasing and healthy environment. Possibly policy changes should be made to shift government incentives from clearing more land, which is often marginal for agriculture, to incentives for conservation. Policy changes that look at the total soil resource and development of land allocation procedures that encourage conservation of the best land for each resource user should be examined.

So far most of the issues I have raised have been rather negative. As the students at this workshop have pointed out, we should be positive. I agree. There are positive aspects that have emanated from this workshop. One of the main positive apsects is that the workshop was held, with good attendance, and we freely and openly raised and discussed issues. We have begun to increase our communication and awareness. Another positive aspect is that we are continuing to broaden our approaches to soil degradation by involving agriculturists, foresters, engineers,

economists, public sector, private sector and educational institutions in discussions of the problems. Possibly another bright light is that educational institutions and those involved in extension will be better equipped to communicate the problems to their constituents. I also believe that this workshop has done much to make us aware that we cannot solve soil degradation problems alone. We need the help of our colleagues in related disciplines.

APPENDICES

APPENDIX I

WORKSHOP PROGRAM

THURSDAY, FEBRUARY 17

8:30-9:30 Registration and Coffee

9:30-9:45 Opening Remarks
- N. Sprout, B.C. Land Resource Sci. Lead Comm.
- T. Windt, B.C. Engin. Lead Comm.

9:45-10:35 Soil Degradation in Canada, an Overview
- D. Coote, Land Resource Research Inst., Ottawa

10:35-11:00 COFFEE

11:00-11:30 Soil Degradation in Forestry in B.C.
- W. Young, Chief Forester, B.C. Min. of Forests

11:30-12:00 Soil Degradation in Agriculture in B.C.
- S. Peterson, Deputy Min. B.C. Min. Agric. & Food

12:00-1:00 LUNCH

1:00-1:20 Degradation Effects of Soil Erosion by Water and Wind
- L. van Vliet, Agr. Canada
- M. Novak, U.B.C.

1:20-1:40 Degradation Effects of Acidification
- P. Hoyt, Agr. Canada Summerland

1:40-2:00 Degradation Effects of Organic Matter Loss
- J. Keng, Agr. Canada
- L. Lowe, U.B.C.

2:00-2:20 Degradation Effects of Soil Compaction
- J. de Vries, U.B.C.

2:20-2:40 Subsidence of Organic Soils
- G. Wood, B.C. Min. Agr. & Food, Cloverdale

2:40-3:00 Degradation Effects of Improper Water Management
- M. Driehuyzen, B.C. Min. Agr. & Food, Cloverdale

3:00-3:15 DISCUSSION

3:15-3:30 COFFEE

3:30-3:50 Degradation Effects of Linear Development
- G. Miller, B.C. Hydro

3:50-4:10 Degradation Effects of Land Clearing
- R. Kline, B.C. Min. Agr. & Food, Prince George

4:10-4:30 Degradation Effects of Forest Harvesting and Site Preparation
- T. Ballard, U.B.C.

4:30-4:50 Access Road Related Degradation Problems in Forestry
- B. Carr, U.B.C.

4:50-5:10 Degradation Effects of Mass Movement
- J. Ryder, Consultant, Vancouver

5:10-5:30 Towards Soil Conservation in B.C.
- R. Bertrand, B.C. Min. Agr. & Food, Cloverdale

5:30-5:45 DISCUSSION

FRIDAY, FEBRUARY 18

8:00-12:30 Soil Degradation Tour
- Forestry related degradation problems, Vedder Mountain
- Flooding and Wind Erosion, Fraser River Flood Plain and Sumas Prairie
- Erosion, tillage,compaction problems in Matsqui Municipality

12:30-1:30 LUNCH

1:30-3:00 Workshop Groups

3:00-3:30 COFFEE

3:30-4:15 Workshop Groups Conclusions

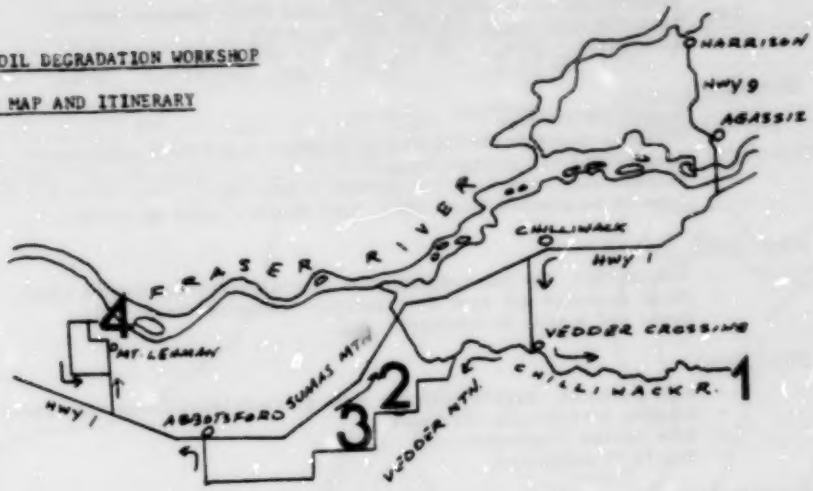
4:15-4:35 Summation and Perspective
- L.M. Lavkulich, U.B.C.

APPENDIX II

SOIL DEGRADATION TOUR OF FEBRUARY 18, 1983

B.C. SOIL DEGRADATION WORKSHOP

TOUR MAP AND ITINERARY



Please try to board the buses in time for departure at 8:00 AM sharp!

Harrison to Vedder Crossing. We travel across the floodplain of the Fraser River. The soils are dominantly medium to moderately fine-textured and poorly to very poorly drained. High water levels in the winter cause flooding, which results in some runoff and erosion, and structural damage to surface soils. Some of these effects can be observed along the way.

Vedder Crossing to Site 1. We travel up the Chilliwack River valley where the forested soils are mainly coarse-textured glaciofluvial and till deposits, with localized loess capping and small areas of moderately fine lacustrine materials. Degradation effects at the forest site are outlined in a separate handout.

Sumas Prairie, Sites 2 and 3. Returning to Vedder Crossing, we enter Sumas Prairie, a sandy lacustrine plain reclaimed in the 1920's by draining Sumas Lake. The plain is extensively drained, mostly by open ditches. Water tables are kept high in the summer months to provide sub-irrigation. Winter flooding causes runoff and erosion visible at Site 2. Other degradation effects here are structural degradation due to flooding, excessive tillage, compaction and declining organic matter levels. At site 2 the soils are 20 to 50 cm of silty clay loam overlying medium sand. Wind erosion is a problem in Sumas Prairie, when surface soils are dessicated by high winds. At Site 3 the soils are mainly loamy sand, and are more typical of the soils of the area. They have little or no structure and very low organic matter levels. Note the deposition of lighter-colored sand in furrows, and the general deflation and scouring of the surface caused by wind as well as by rainfall.

Abbotsford to Site 4. We travel through Matsqui uplands, where the soils are dominantly glaciomarine and till, with varying depths of loess capping. Subsoils are generally slowly permeable, and water storage capacities in the surface soils is very low, leading to quick saturation, runoff and erosion in the winter months. Excessive tillage, lack of cover crops and orientation of crop rows up and down the slopes contribute to water erosion throughout the area.

Site 4. Tour of Ministry of Agriculture and Food D.A.T.E. Project, Soil Erosion Control and Runoff Water Management Demonstration. Note the many examples of water erosion, the effectiveness of underdrainage, cover crops and mulches. Compare soil profiles below and between crop rows, noting the effects of tillage and compaction.

Return to Harrison. Lunch enroute. Note more examples of erosion in the uplands, flooding in lowlands.

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B. C. SOIL DEGRADATION TOUR - SITE NO. 1

Overview

- Biogeoclimatic subzone - CWHa, Douglas Fir - Western Hemlock
- Edatopic Grid range 1-6/C-E Average 3-4/D
- Site Index - Type 1 - 49 ±; Type 2 - <42.

Stop #1

- Scarification area
- Original Stand Dr Mb (Hw Cw) established after 1938 wildfire
- Area logged via skidder 1981-82
- Mechanically scarified - windrowed - Fall 1982
- Area to be planted March 1983, Site Specific with Bg Cw Fd.

Lower Bench

- Undulating; Aeolian capping over fluvial/glaciolacustrine clays
- Water drainage and root restrictive; compacted basal till
- Mesic and hygric to subhygric.

Upper Bench

- Kame Terrace; Aeolian capping over glaciofulvial/lacustrine clays
- capping variable in thickness
- more coarse fragments
- Hygric to subhygric.

Scarification Area to East (off map)

- Kame Terrace; no capping
- Colluvial elements
- Parent material root and water restricting; compacted basal till.

Degradation Problems

- Evidence of severecompaction
- Capping and clays intermixed
- Aeration quality of soil disturbed
- Low bulk density degraded
- Expecting minor gullying from erosion
- Sub-surface seepage water brought to surface in places creating localized puddling; impeded drainage.
- failing cutbanks along upper road to east (off map)

Stop #2

- Proposed Site Rehabilitation Area
- Original Stand Mb Fd Cw (Dr)
- Area logged via skidder 1981
- Area to be Site Rehabilitated 1984-85; herbicide (Roundup) and burn
- considering ripping all existing skid roads as 15 - 20% of area covered by skid roads reducing site productivity.
- B.C.F.S. Engineering layed out main haul road and proposed landings to north of timber type
- Area to be planted March 1985, Site Specific with Fd Bg Cw.

Degradation Problems

- 15 - 20% of areas' site productivity reduced due to profusion of skid roads
- expecting minor gullying from erosion
- sub-surface seepage water brought to surface
- skid roads altering drainage pattern slightly.

Stop #3

- Plantation
- Original Stand Dr Cw Mb (Fd)
- Area site prepared for planting by Work Activity Program (Human Resources, Forestry Co-operative Program) Winter 1976-77
- Area planted with Fd Cw spring 1977 utilizing Inmate labour
- Plantation maintained by Work Activity Program; manual brushing once per year 1978, 1979, 1980, 1981
- Fd off-site due to edatopic grid
- heavy slash accumulation makes further manual treatment hazardous.

Province of British Columbia
Ministry of Forests
FOREST SERVICE

EXHIBIT A

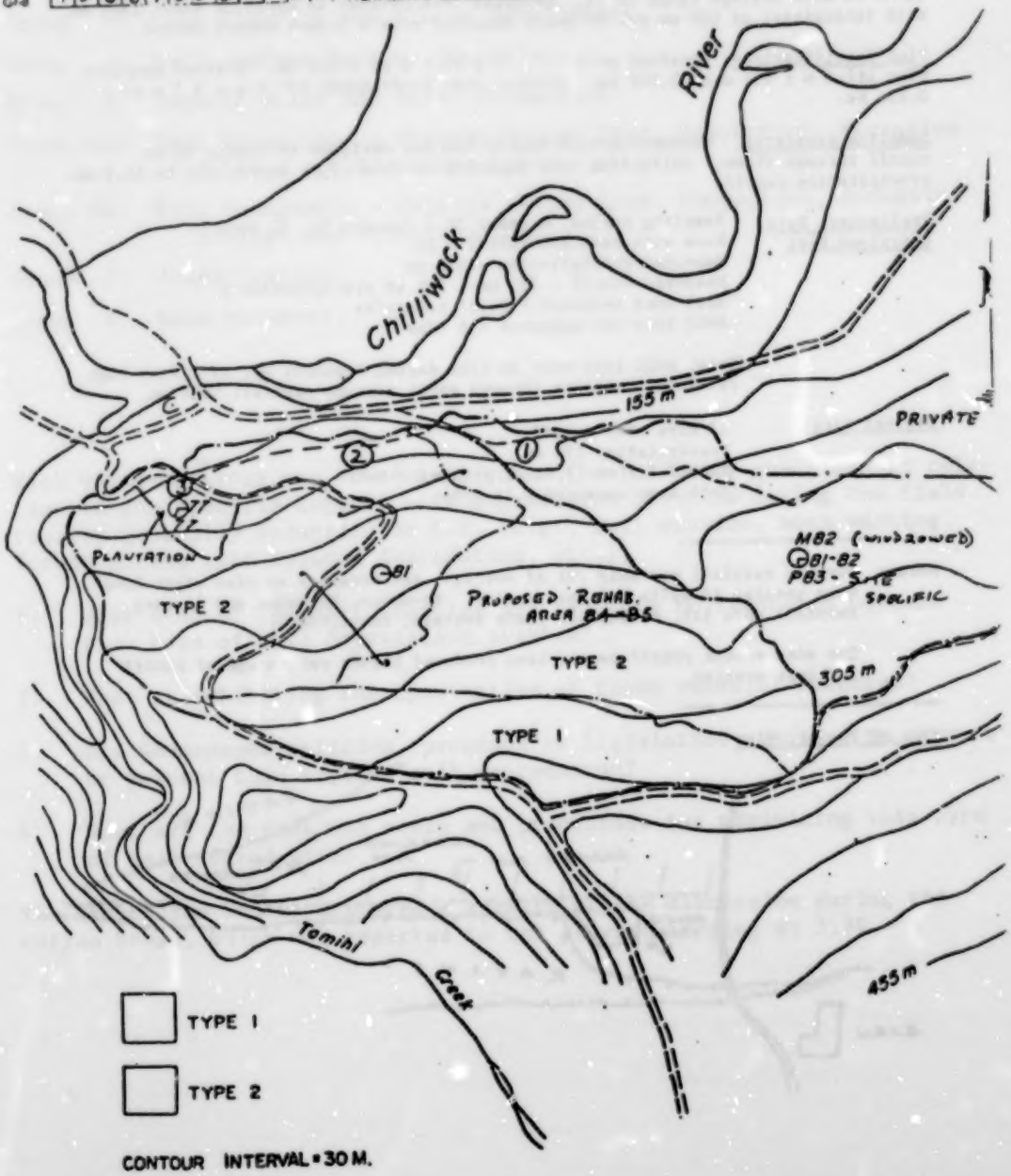
Date FEBRUARY 10, 1983
Ref. Map
Base 92H-001
Scale 1: 10,000

Map Of B.C. SOIL DEGRADATION TOUR - SITE NO. 1

Outlined ——·——·—— Area ..... hectares ?

UTM Grid	Zone	East	North	Reg	Compl	L
	10	587000	5436000	11	-43	-

Forest Region VANCOUVER
District CHILLIWACK
Land District NEW WESTMINISTER



F.S. 357 (Revised June, 1979)-n

B.C. SOIL DEGRADATION WORKSHOP TOUR SITE NO. 4 (D.A.T.E. PROJECT)

PROJECT SPECIFICATIONS AND PRELIMINARY DATA

Site Characteristics. Whatcom-Nicholson-Scat soils, disturbed by recontouring. Typically 15 to 30 cm SiL, weak fine granular structure, less than 5% O.M., overlying variably permeable, weakly stratified SiCL glaciomarine material. Slopes vary from 5% to 9% with average slope of 7%. Rainfall from October to April is about 1200 mm, with intensities of 100 mm per 24 hours expected with a 2-year return period.

Plot Specifications. Drained area 167.6 m x 11.6 m or 0.194 ha. Drained sampling plot 167.6 m x 6.1 m or 0.102 ha. Control plot (undrained) 137.2 m x 3.7 m or 0.050 ha.

Sampling Apparatus. Coschocton-type Runoff Sampler designed to sample 1% of runoff through flume. Collecting tank capacity 75 liters, or equivalent to 14.9 mm precipitation runoff.

Preliminary Data.
Undrained Plot

Sampling period, October 30 - January 31, 92 days
Days with rain and runoff - 52
Measured precipitation - 670 mm
Measured Runoff - 123 mm (24% of precipitation)
Soil loss measured - 24.67 tonnes/ha
Soil loss not measured - 6 t/ha

Total soil loss over 30 t/ha during 3 months out of 7 with high rainfall. October through April average rainfall 1200 mm.

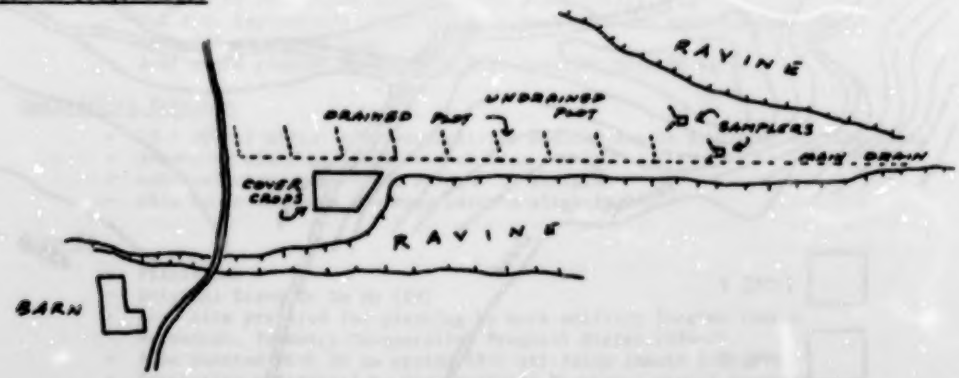
Drained Plot

17 days with runoff
Precipitation 179 mm
Runoff 3.7 mm (1.9% of precipitation)
Soil loss measured 0.14 t/ha

Notes: October rainfall was only 72% of average, and November erosion might have been greater if soils had been wetter. November, December and January rainfall were 11%, 6% and 44% above average, respectively.

The more recent runoff events have produced higher percentage of runoff but less erosion.

Plan of Project Site



APPENDIX III

WORKSHOP GROUPS AND GUIDELINES

Group 1: Soil Degradation Effects of Forest Site Preparation and Harvesting.

Group 2: Forest Access Road Related Soil Degradation.

Group 3: Land Clearing and Linear Development.

Group 4: Soil Surface Erosion (Water).

Group 5: Organic Soils and Water Management.

Group 6A: Soil Management - Organic Matter Loss, Compaction, Excessive Tillage and Structure Loss.

Group 6B: Soil Management - Organic Matter Loss, Compaction, Excessive Tillage and Structure Loss.

Group 7: Acidification.

Group 8: Mass Movement.

Each workshop group was asked to discuss the following questions in relation to the specific type of soil degradation observed during the field tour or generally occurring in B.C. (e.g., soil erosion, mass wasting, forest access road related degradation, etc.).

1. What kind of remedial measures are feasible to reduce or correct this type of soil degradation problem?

2. What is inhibiting the application of these remedial measures?

3. Are Government policies, programs or legislation required to correct or prevent this type of soil degradation?

4. What are the research needs and priorities for minimizing this type of soil degradation?

The discussion leader prepared a summary of the discussion during the coffee break, which was reported to the general meeting at 3:30.

APPENDIX IV

LIST OF PARTICIPANTS

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Back Cover: Rill erosion in a newly established pasture in the Lower Fraser Valley. The erosion is partly due to seepage from the field above it.
Courtesy: R.C. Wood, BCMAF